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Effectiveness of Surface Mine Sedimentation Ponds

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In general, poor construction and inadequate maintenance of these ponds were found to be the major problem areas. The ponds had generally higher removal efficiencies during the baseline sampling period and much lower efficiencies during the storm event. The theoretically predicted efficiency of the ponds was essentially the same as the actual efficiency under baseline conditions. During the rainfall event, there was generally little or no correlation between the theoretical and actual efficiencies. The predicted efficiencies were found to be much higher than the actual efficiencies during the rainfall event in most cases.

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EFFECTIVENESS OF SURFACE MINE SEDIMENTATION PONDS

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the pollutional impact on our environment and even on our health often requires that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-CI) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This study was conducted to determine the effectiveness of sedimentation ponds in the removal of suspended solids discharged in the runoff from land disturbed by surface mines. As discussed in this report, pond performance approached that predicated by theoretically "trap" formulas under low flow conditions, but performed poorly under high flow conditions. Part of the inadequate performance was due to poor construction and maintenance. The information in this report should be of interest to any program concerned with suspended solids control in runoff. The Extraction Technology Branch of IERL-CI proposes to follow this study with further developmental work on sediment ponds.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

An in-field evaluation of the effectiveness of sediment ponds in reducing suspended solids in the runoff from surface mining activities was performed. Nine selected sedimentation ponds in the three eastern coal-mining States of Pennsylvania, West Virginia, and Kentucky were sampled under two different operating conditions--a baseline and a rainfall event. Their theoretical and actual efficiency of removal of suspended solids were computed and compared.

In general, poor construction and inadequate maintenance of these ponds were found to be the major problem areas. The ponds had generally higher removal efficiencies during the baseline sampling period and much lower efficiencies during the storm event. The theoretically predicted efficiency of the ponds was essentially the same as the actual efficiency under baseline conditions. During the rainfall event, there was generally little or no correlation between the theoretical and actual efficiencies. The predicted efficiencies were found to be much higher than the actual efficiencies during the rainfall event in most cases.

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SECTION I

INTRODUCTION

Surface mining of coal involves the removal of vegetation, earth, and rock in order to uncover the underlying coal deposits. As a consequence of this massive earthmoving operation, large areas are subject to accelerated erosion of unstabilized soil. Without controls, this soil would eventually be carried by surface runoff into the natural waterways. To prevent the environmental deterioration of natural streams and waterways, many states have enacted laws and regulations requiring that the discharge from mining operations meet certain effluent standards and/or criteria. Several States, including Pennsylvania, West Virginia, and Kentucky, have regulations that require the construction of sediment ponds to control the runoff from surface mines. These ponds are primarily intended to trap the suspended solids generated from the mining activity.

Even though there are over 200 sediment ponds in operation at the present time, the documentation of the effectiveness of these ponds for removing suspended solids is limited. There are conflicting opinions on the actual effectiveness of these sediment ponds, but the general consensus is that overall the sediment basins are highly effective. The U.S. Soil Conservation Service (SCS) indicates that if their design criteria are followed, a trap efficiency (i.e., the percentage of incoming sediment which remains in the pond) of at least 75 percent should be attained.[1] Other studies have indicated that trap efficiencies of 85 percent and higher have been obtained.[2] However, the data for the above trap efficiency estimates are rather sketchy. A rigorous analysis of the various aspects that govern sedimentation basin performance based on actual field data, especially in the field of surface mine sedimentation control, was not previously available.

Consequently, a study was conducted to quantitatively determine the effectiveness of a number of surface mine sedimentation ponds in reducing suspended solids in the runoff from surface mining activities. In all, nine surface mine sedimentation ponds in three eastern coal mining States, Pennsylvania, West Virginia, and Kentucky, were selected for field evaluation. Two ponds were selected in Pennsylvania, one pond in northern West Virginia, two ponds in the steep slopes of southern West Virginia, two ponds in eastern Kentucky, and two ponds in western Kentucky. Under these overall geographic constraints, the ponds were selected so that a variety of different physical characteristics could be studied. The selected ponds represented a broad spectrum of the type, location, topography, soil type, and usage by the coal mining industry of the ponds within the eastern United States. Ponds representing the best in the state-of-the-art were to be selected for study.

As-built measurements of each pond and its appurtenances were taken. Water samples during a baseline (nonstorm) period and during a rainfall event were collected, and flow measurements were taken at both the inflow to and outflow from the ponds. Based on the field observations, the actual removal efficiency of the ponds was determined and compared to its theoretical efficiency as computed by Stokes' Law.

The overall objectives of the project were to obtain and document the effectiveness of various types of sedimentation ponds normally used in surface mining operations, determine their shortcomings, and develop recommendations for design and maintenance procedures which will maximize suspended solids removal.

SECTION II

CONCLUSIONS

An in-field evaluation of the effectiveness of sediment ponds in reducing suspended solids in the runoff from surface mining activities was performed. Nine selected sedimentation ponds in the three eastern coal-mining States of Pennsylvania, West Virginia, and Kentucky were sampled under two different operating conditions, a baseline and rainfall event. Their theoretical and actual efficiencies of removal of suspended solids were computed and compared.

The sedimentation ponds which were properly utilized and maintained were measured to have high efficiencies of removal of suspended solids during the baseline sampling period. Ponds which were not properly utilized or maintained had deficiencies which contributed to their poor removal efficiencies. These deficiencies included such things as a water supply pump intake located near the outflow riser or an eroded emergency spillway.

Generally, the efficiency of removal of suspended solids was measured to be much lower during the storm event as compared to during the baseline condition.

In general, the ponds were found not to be constructed in accordance with the approved plans and specifications. This contributed to poor pond performance. For instance, in one pond the top of the normal overflow riser was constructed higher than the crest of the dam, resulting in frequent use of the emergency spillway. This caused severe erosion and downstream damages. In addition, once the ponds are constructed, they were found to be poorly maintained. Timely removal and disposal of the accumulated sediments, cleaning of clogged outflow pipes, repair of emergency spillways and embankment repair are extremely important for the proper functioning of the whole sedimentation pond system, but were usually overlooked.

Off-channel, dugout-type ponds, similar to the ones commonly used in Pennsylvania where water is pumped from the mining pit to the pond, are more effective and have less need for maintenance than the ponds which are built in the main stream channel. This is primarily due to the fact that no direct surface runoff enters the off-channel ponds and the inflow rate can be controlled by the rate of inflow pumping. Also, the pit area from where the water is pumped acts as a primary settling basin. However, because of physical, topographical, or geographical constraints, the construction of the off-channel, dugout-type of pond may not be feasible in all cases, especially in steep mountainous terrain, but should be encouraged wherever possible. The main disadvantage of the use of the dugout-type ponds in Pennsylvania is that they do not intercept the runoff from all of the disturbed land. The runoff from the slopes of the spoil piles which face away from the pit never enters the ponds. Thus, an additional pond or other sediment control device would have to be placed so that the sediment generated from these slopes would also be controlled.

It appears that if sediment ponds are built to have approximately a 10-hour detention time or an overflow velocity of less than 2×10^{-5} m/sec, high efficiencies of removal of suspended solids will result. This is assuming, of course, that the ponds are adequately maintained throughout their life.

The problem of resuspension of settled sediment was not observed in most of the ponds where their depth was greater than 1.0 m (3.3 ft). Therefore, maximizing the surface area and maintaining a minimum depth of about 1.0 m (3.3 ft) at all times will result in better performance of the pond.

Approximately one-half of the ponds surveyed did not meet the State or proposed Federal effluent standards during the measured baseline and storm conditions. It is recognized that additional factors such as high intensity storms occurring at the time of sampling and non-typical inflows at the time of sampling could have influenced the results obtained during this program. However, field observations indicate that construction of the ponds not in accordance with approved plans and specifications and poor subsequent maintenance of the ponds were the two major factors contributing to their poor performance.

Ponds built in the stream channel are frequently left in place after the mining activities are completed. Trapped sediment, along with the added volume of the embankment, may eventually be carried into the natural waterways when failure of the dam occurs during high flood flows. The problem of excessive sedimentation of downstream areas is therefore, only postponed - not reduced. Thus, provisions for stabilization of the pond area should be a part of the overall pond plan.

The computed theoretical efficiency of the ponds that were properly utilized and maintained was essentially the same as the measured suspended solids removal efficiency for the baseline conditions. During the rainfall event, however, there was generally little or no correlation between the theoretically predicted efficiencies during the rainfall event. During this study, the low measured efficiencies during the rainfall event were, in most cases, directly attributable to improper construction and maintenance of the ponds.

Many deficiencies are inherent in the use of Ideal Settling Theory for predicting pond settling efficiency. The theory does not adequately consider such things as the location of the inlet and outlet, shape of pond, and depth of water in the pond. However, much information is available on parameters such as the design of inlets and outlets, pond shaping, etc., as presented in Section VIII of this report, which should be utilized in constructing sediment ponds.

Good mine reclamation practices are essential to reduce the suspended solids content delivered to the pond.

In order to increase the suspended solids removal efficiencies of sediment ponds, additional measures such as trash barriers or velocity checks at the inlets and non-perforated risers should be utilized wherever possible. In order to meet effluent standards, flocculants may also have to be used in some cases. Also, a procedure for the documentation of the maintenance requirements of the sediment ponds needs to be established.

The State design standards currently used in Kentucky and West Virginia are the most thorough and are good for use as general design and construction guidelines, but they are deficient in the following areas:

(1) Maintenance and repair of the pond during and after the mining operation

(2) Disposal of sediment during and after the mining operation

(3) Dismantling of the pond after mining operations have ceased

(4) Design of a sediment pond to achieve a specific water quality criterion.

SECTION III

RECOMMENDATIONS

POND DESIGN AND MAINTENANCE

The criteria for the design of sediment basins are derived from the Soil Conservation Service design practices, which are based on the retention of a percentage of the total suspended solids. Since a large number of States have already adopted water quality criteria, the design of sedimentation basins should be based on the removal of solids to meet a specific water quality standard. It is recognized that these designs will have to be referenced to a storm of a specific return interval.

In view of the problem of deficient State design standards in the areas of maintenance and repair of the ponds, disposal of sediment, dismantling of the pond after mining has ceased, and reclamation of the area where the pond was built, it is recommended that these additional points be addressed in the State standards.

All State regulations reviewed require cleaning of the pond after a certain portion of the capacity is used-up. However, no records of sediment accumulation are kept. It is essential, therefore, that records of all sedimentation ponds be kept with information such as when they were built, when cleaned, when repaired, etc. included in the records. In addition, simple, visual methods such as a mark or metal plate on the outflow riser should be used to notify the inspector when pond cleaning is required.

Alternative overflow devices, such as the siphon draw pipe or a riser with perforations on only a portion of its length down from the top should be considered for use instead of the standard, perforated riser. These alternative overflow devices have the capability of reducing the amount of suspended sediment in the pond outflow.

Recognizing topographical constraints, it is recommended that the construction of off-drainage sedimentation ponds be considered first in the design of a surface mine sedimentation pond. It is recognized, however, that the spoil pile slopes on the opposite side of the pit in area mining operations will need an additional sediment control device installed downslope of them.

Unless specific site conditions warrant a more conservative design, it is recommended, based on the results of this study, that sediment ponds for surface mines be designed and constructed to have at least a 10-hour detention time or an overflow velocity of less than 2×10^{-5} m/sec for the design storm.

It is also recommended that the ponds be designed and constructed based on field-run topographic maps. Most of the ponds investigated were designed and constructed based on simple enlargements of U.S.G.S. topographic maps. These proved to be inadequate and accounted for many inadequate and/or inefficient designs and many construction versus design discrepancies. It is further recommended that these field-run topographic maps be at two-foot contour intervals on flat or gentle slopes and at five-foot contour intervals on steep slopes.

RESEARCH REQUIREMENTS

All nine selected ponds were sampled during only two different operating conditions, a baseline and a rainfall event. Since only these two discrete sampling periods were used to evaluate the performance of the ponds, the results may not be representative of the long term performance of the ponds. Thus, evaluation of the ponds based on an extended sampling period needs to be done to provide statistically sound data.

Timely and adequate maintenance of sediment control structures is vital to insure their proper functioning. The quality of the effluent in all cases could have been improved with proper maintenance of the ponds. A comparison study of the normally maintained ponds versus the ponds maintained under optimum maintenance is necessary to correctly evaluate the effectiveness of these ponds.

Outflow from the pond through a perforated riser allows fine sediment to be carried away through the perforations. Further study is necessary to investigate the alternative outflow devices such as the siphon draw pipe which is currently being used in the State of Maryland or outflow risers with perforations only part of the way down from the top.

The States of West Virginia, Kentucky, and Maryland currently have sediment pond design standards which specify a minimum storage volume per unit area of disturbed land. Further research needs to be performed to verify that these specifications are safe design criteria and to evaluate which storage factors are the most realistic.

It is recognized that many factors enter into how much suspended sediment is removed by a pond. Some of these factors include the return interval of the storm, the pond detention time, the storage available, and the antecedent soil moisture. Additional research should be performed to further evaluate the effects these factors have on pond performance.

SECTION IV

STATE REGULATIONS AND DESIGN PRACTICES

The initial phase of this study involved the review of State regulations and design practices with respect to the control of sediment from surface mining operations. Since the nine study sites under this program were located in three eastern coal mining States of Pennsylvania, West Virginia, and Kentucky, the main emphasis of this phase of the study was placed on these three States. However, the rules, regulations, and design practices for sediment basins utilized by other eastern States and agencies were also reviewed. These included those of Maryland, Ohio, Indiana, Illinois, Virginia, Tennessee, and the Tennessee Valley Authority (TVA).

LEGISLATION

Existing State laws do not directly address the utilization, design, and operation of sedimentation ponds. In general, the laws serve the following functions:

(1) Assign responsibility for the supervision of surface mining and reclamation activities to a specific agency.

(2) Define the terminology associated with surface mining and reclamation activities.

(3) Define the responsibility and duties of the responsible agency and its personnel.

(4) Define the necessary requirements for conducting surface mining and reclamation activites within the State.

(5) Outline the penalties for violating the promulgated laws.

The responsible agencies and applicable laws related to the use of sedimentation basins in surface mining activities in the States of Kentucky, Pennsylvania, and West Virginia are listed in Table 1.

REGULATIONS AND DESIGN CRITERIA

Design criteria and specifications for sedimentation ponds utilized in conjunction with surface mining activities have been developed for all three States where study sites are located. Such items as the construction details, size, number, and location of these structures are specified by regulations. The extent and depth to which these design considerations and regulations are addressed in the various States varies considerably. In general, the criteria follow the design procedures developed by the U.S. Soil Conservation Service (SCS) for sediment basins.[1] This fact is not surprising since in both Kentucky and West Virginia the criteria were developed with the assistance of the SCS. A comparison of the various elements related to the design, construction, and maintenance of sediment ponds in the states of Kentucky, Pennsylvania, and West Virginia is presented in Appendix A. Also presented in Appendix A are brief summaries of the status of regulations that pertain to the use of sedimentation ponds in conjunction with surface mining activities in other eastern States and agencies.

FEDERAL AND STATE EFFLUENT STANDARDS

Most States have adopted water quality standards for discharges from surface mining activities. The various standards consider all or some of the following parameters as being important with respect to surface mining activities:

(1) Suspended solids

(2) pH

(3) Total iron

(4) Alkalinity

(5) Toxic material

(6) Oils and grease

Table 2 compares the State effluent standards for the surface mining industry for the States in which the study ponds were located, with the current preliminary Federal effluent guidelines.[3]

Table 1. STATE LAWS AND REGULATIONS RELATED TO UTILIZATION OF SEDIMENTATION BASINS IN SURFACE MINING OPERATIONS

State	Applicable laws	Promulgated rules and regulations	Responsible agency
Kentucky	Chapter 350, Title XXVIII Kentucky Revised Statutes Effective: Jan. 1, 1973	Kentucky Department for Natural Resources and Environmental Protection, Strip Mining Regulations	Department for Natural Resources Division of Reclamation
Pennsylvania	Surface Mining Conservation and Reclamation Act Effective: Jan. 1, 1972	Pennsylvania Department of Environmental Resources, Standard Conditions Accompanying Permits Authorizing the Operation of Coal Mines, March 31, 1967	Department of Environmental Resources, Bureau of Land Protection & Reclamation, Division of Mine Reclamation
West Virginia	Article 6 and 6A, Chapter 20, Code of West Virginia Effective: Mar. 13, 1971	West Virginia Surface Mining/Reclamation Regulations, Department of Natural Resources Chapter 20-6, Series VII, (1971)	Department of Natural Resources, Division of Reclamation

Table 2. EFFLUENT STANDARDS FOR THE SURFACE MINING INDUSTRY

State	Turbidity or suspended solids	pH	Total iron	Alkalinity	Toxic materials	Oils & grease
Federal	30-100 mg/l	6.0-9.0	4.0-7.0 mg/l	Greater than acidity	*	+
Kentucky	150 JTU's[ϕ]	6.0-9.0	7.0 mg/l or less	Greater than acidity	---	---
Pennsylvania	ξ	6.0-9.0	7.0 mg/l or less	---	---	---
West Virginia	1000 JTU's or less#	5.5-9.0	10 mg/l or less	---	---	---

* No toxic or hazardous material as designated under the provisions of Section 12 of the Federal Water Pollution Control Act or known to be hazardous or toxic by the permittee except with the approval of the Regional Administrator (EPA) or his authorized representative.

+ Final resolution of this parameter must await discussion with the oil industry. After resolution, it will be applied to all industry on a relatively uniform basis. Present thinking is that it may be a single number no more stringent than 5 mg/l and no less stringent than 10 mg/l as a final effluent limit. The use of dilution to achieve this number will not be allowed.

ϕ The discharge shall contain no settleable matter, nor shall it contain suspended matter in excess of 150 Jackson Turbidity Units, except during a precipitation event, which the operator must show to have occurred, in which case 1000 Jackson Turbidity Units may not be exceeded.

ξ No silt, coal mine solids, rock debris, dirt, and clay shall be washed, conveyed, or otherwise deposited into the waters of the Commonwealth.

# Turbidity--not more than 1000 Jackson Units (JU) of turbidity 4 hours following a major precipitation event and not more than 200 JU after 24 hours (major precipitation event = 1/2 inch of rainfall in 30 minutes).

SECTION V

POND SELECTION AND EVALUATION

SELECTION OF STUDY PONDS

Most of the surface mining activity in the eastern United States is concentrated in the three States of Pennsylvania, West Virginia, and Kentucky. The selection of sedimentation ponds for in-field evaluation was, therefore, confined to these three States. The intention was to select a total of nine surface mine sedimentation ponds according to the following geographical distribution: two ponds in Pennsylvania, one pond in northern West Virginia, two ponds in the steep slopes of southern West Virginia, two ponds in eastern Kentucky, and two ponds in western Kentucky. Selection was accomplished as follows.

First, the cognizant agencies in the three States, including the Kentucky Division of Reclamation; the West Virginia Department of Natural Resources, Division of Reclamation; and the Pennsylvania Department of Environmental Protection were contacted for their recommendations on potential candidate sites in their respective jurisdictions. Figure 1 is a map of these three States with the distribution and number of sedimentation ponds recommended, by county, within the three States.

Designs, construction drawings, and other pertinent information which is conventionally submitted by the mine operators to the State agencies were obtained and reviewed. The list of initially recommended sites was narrowed down to a small number which could be thoroughly investigated in the field. Based on the results of the initial field reconnaissance of these and some additional ponds which were suggested by the field inspectors in those areas, final selection of nine ponds was made. The ponds were selected to satisfy the following criteria:

(1) The selected ponds represent a range of:
    (a) Size
    (b) Topography in which they are built
    (c) Soil types in which they are built

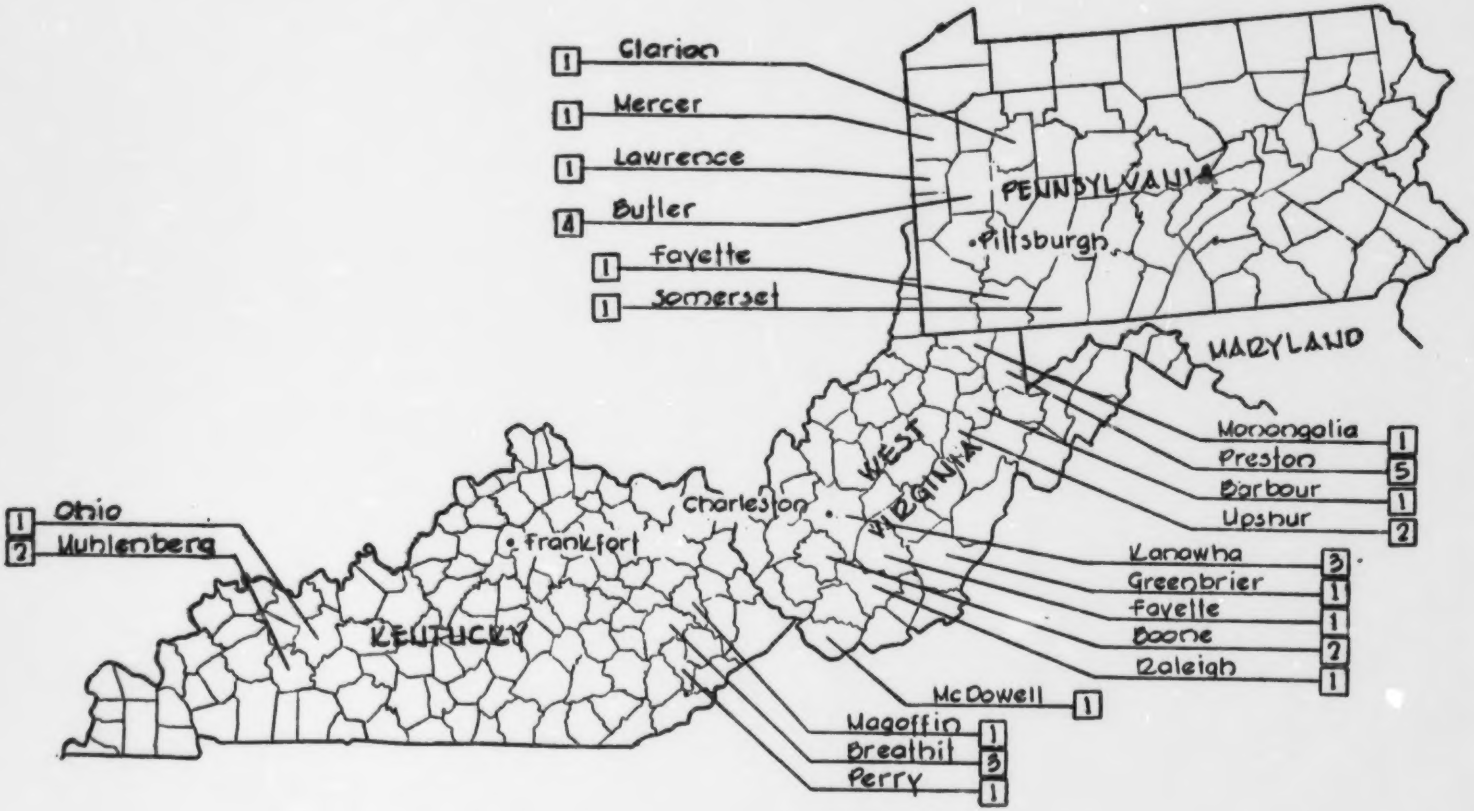

1 Clarion
1 Mercer
1 Lawrence
4 Butler
1 Fayette
1 Somerset
PENNSYLVANIA
Pittsburgh
MARYLAND
Monongalia 1
Preston 5
Barbour 1
Upshur 2
WEST VIRGINIA
Charleston
Kanawha 3
Greenbrier 1
Fayette 1
Boone 2
Raleigh 1
McDowell 1
1 Ohio
2 Muhlenberg
Frankfort
KENTUCKY
Magoffin 1
Breathit 3
Perry 1

FIGURE 1. Distribution of Initially Recommended Ponds

    (d) Mining procedure used in the tributary watershed

(2) All sediment control structures be approved by the cognizant State agency

(3) Selected ponds be representative of the typical construction used in the area

(4) Mining activity exist during the course of the study

(5) The site be accessible for sampling

FIELD INVESTIGATION OF SELECTED PONDS

The main objective of this study was to evaluate and determine the actual efficiencies of the selected ponds in removing suspended solids from the influent. The actual efficiencies were then compared to the design criteria and the theoretically predicted efficiencies. To achieve this objective the field investigations were subdivided into two parts: As-built measurements and water sampling.

As-Built Measurements

The designs and drawings prepared for the sediment ponds normally use U.S.G.S. quadrangle maps as a base. Actual topographic surveys and establishment of horizontal and vertical controls for construction are seldom performed. Therefore, the actual construction of the structures and their location is sometimes different from the exact location shown on the drawings. Therefore, measurements were taken to determine any differences between the design drawings and actual construction of the selected ponds.

The following main parameters which influence the performance efficiency of the sedimentation ponds were measured for each of the nine ponds:

(1) Size and geometry of the pond to determine its surface area

(2) Size, location, and material of the inflow and outflow structures

(3) Sediment accumulation

    (a) Depth of water
    (b) Depth of sediment

Water Sampling

Water quality samples were collected and flow measurements taken at both the inflow to and outflow from each pond. The samples were taken during a baseline (nonstorm) period as well as during a rainfall event in order to determine the pond behavior under two different operating conditions. The duration of sampling varied according to the size, shape, and operating conditions present at each pond. The collected influent and effluent samples were analyzed for the following parameters:

(1) Suspended solids

(2) Settleable solids

(3) Turbidity

(4) pH

(5) Specific gravity of the suspended particles

(6) Grain size distribution of the incoming suspended particles

(7) Water temperature

THEORETICAL AND ACTUAL TRAP EFFICIENCIES

Theoretical Analysis

The efficiency of a sedimentation pond is defined as the percentage of incoming suspended matter which is settled in the pond. Theoretical efficiency of the selected ponds was determined by using the Ideal Settling Theory (Stokes' Law). A brief discussion of Ideal Settling Theory and the factors which influence ideal settling is given in Appendix B. In ideal settling the removal efficiency of the suspended solids is dependent upon the following:

(1) The surface area of the basin

(2) The rate of inflow

(3) The horizontal velocity of flow through the basin

(4) Settling velocity of the particles

Also, the depth of the basin will have some influence, depending on whether or not horizontal velocity is maintained below the scour velocity.

The critical settling velocity of the smallest size particle settled in each sediment pond was computed based on the measured flow rate and the surface area of the basin. The smallest size particle which would settle with the calculated velocity was determined by using Stokes' Law (see Appendix B). The percentage of this size particle in the incoming sediments to the basin will give an indication of the expected removal efficiency of the basin.

Actual Efficiency

The percentage of solids actually removed by a particular sediment basin was determined by using the formula:

$$R \text{ (\% solids removed)} = \left[1 - \frac{\frac{10^6}{C_1} - 1}{\frac{10^6}{C_2} - 1} \right] 100 \qquad (1)$$

where C_1 = solids concentration of influent, mg/l

C_2 = solids concentration of effluent, mg/l

The formula was originally derived from a simple mass balance for a conventional dredged material containment basin[4].

The suspended solids concentration in the influent and effluent for use in the formula were obtained from the inflow and outflow water quality samples taken during the course of the field surveys of each pond.

SECTION VI

DESCRIPTION OF SELECTED PONDS

The physical characteristics of all selected ponds at the time the sampling program was conducted are presented in Table 3. A brief description of each pond, including the observed conditions at the time of sampling and an identification of the problems associated with each pond follows.

POND NUMBER 1

This is a combination of two rectangular dugout ponds in series. The mining procedure being used at the site is what is conventionally known as area mining. This procedure is generally used in relatively flat areas where coal seams are roughly parallel to the land surface. The operation is usually started with a box-cut or trench extending to the limits of the property, with a concomitant parallel spoil bank. Spoil material from each successive parallel cut or trench is placed in the preceding trench. The maximum length of the open cut is, however, limited to 457.2 m (1500 ft) according to the current Pennsylvania regulations.

The surface runoff from the active mined areas is collected in the pit and then pumped into the primary settling basin. Water from the 34.5 m x 16.2 m (113 ft x 53 ft) primary pond overflows into a 30.5 m x 16.5 m (100 ft x 54 ft) secondary pond through a 20.3 cm (8 in.) diameter cast iron pipe and finally discharges through a ditch into the natural waterway.

Figure 2 is a drawing of the as-built sediment control ponds. In this type of arrangement, since no surface runoff enters the pond directly, the inflow into the overall system is somewhat independent of the runoff from a rainfall event. Inflow to the ponds is more dependent on the rate of pumping from the pit area. Therefore, in reality, the pit acts as a primary settling area for the sediments from the mining activity.

The construction of these ponds was performed by digging two rectangular pits in the ground at random. The pits were observed to have unstable, unvegetated, and almost vertical

Table 3. CHARACTERISTICS OF SAMPLED PONDS

Pond No.	Location	Pond type	Drainage area (ha)	Average slope*	Type of mining	Nominal surface area (m^2)
1	Pennsylvania	2-rectangular dugout ponds in series	-	Flat	Area mining	1,058
2	Pennsylvania	2-circular dugout ponds in series	-	Flat	Area mining	1,135
3	Eastern Kentucky	Earth embankment with perforated riser	40	Steep	Head-of-hollow fill	1,781
4	Eastern Kentucky	Earth embankment with perforated riser	23	Steep	Mountain top removal	1,023
5	Western Kentucky	Dugout	-	Moderate	Area mining	1,255
6	Western Kentucky	Earth embankment with trickle tube principal spillway	40	Gentle	Area mining	19,045
7	Northern West Virginia	Earth embankment with perforated riser	45	Steep	Mountain top removal	1,101
8	Southern West Virginia	Earth embankment with square drop inlet	78	Steep	Contour	3,670
9	Southern West Virginia	Earth embankment with trickle tube principal spillway	81	Steep	Contour	4,238

* Gentle, 10%; moderate, 10-25%; steep, > 25% .

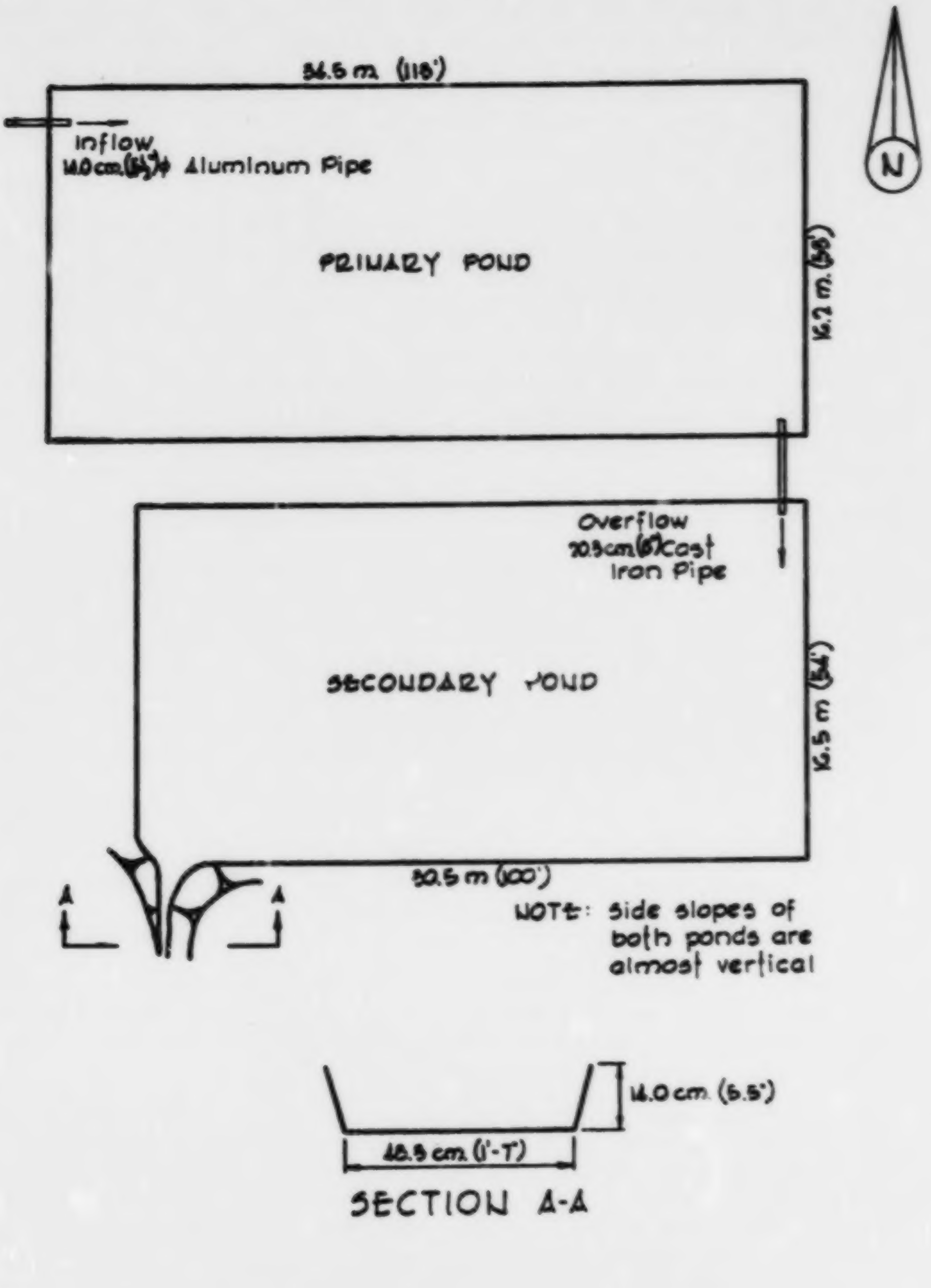

36.5 m (118')
inflow
14.0cm (5½")ϕ Aluminum Pipe
N
PRIMARY POND
16.2 m. (53')
Overflow
20.3cm (8")Cast
Iron Pipe
SECONDARY POND
16.5 m (54')
30.5 m (100')
A
A
NOTE: side slopes of
both ponds are
almost vertical
14.0 cm (5.5")
48.3 cm (1'-7")
SECTION A-A

FIGURE 2. As-Built Drawing of Pond Number 1

side slopes. The depth of the ponds was greater than the designed depth in an effort, according to the inspector, to make them both more effective and longer lasting. Figure 3 is an overall view of Pond Number 1. The as-built ponds were built in contrast to the design drawings which showed 2:1 side slopes, a splash board on the inflow pipe for dissipation of energy, a baffled spillway trough, and a small treatment plant.

The side slopes of the ponds were observed to be unstable. This condition was further aggravated by the soil which had become saturated because of heavy rain for the 12-hour period before collection of the samples. The suspended solids content in the overflow was, in some instances, greater than that in the inflow. This was possibly due to erosion of the pond banks themselves and erosion at the overflow due to high velocity and eddies. In spite of these influences, however, the pond effluent was fairly clean.

POND NUMBER 2

This sedimentation pond is similar to Pond No. 1 except that the two dugout ponds in this case are circular in shape. Area mining is again used in this case. At this surface mine, the surface runoff from spoil areas as well as some undisturbed areas is diverted through diversion channels into the pit area. Thus, this sediment pond system also has the benefit of initial settling of suspended solids in the pit sump area. The water from the pit is pumped into the primary pond through a flexible hose which entered the first pond below water level. Figure 4 shows the sediment ponds. Figure 5 is an as-built drawing of the ponds.

No information on the proposed design and construction of this pond was available from the State agency. This is a fairly old pond and at the time the permit application for this operation was processed, designs and drawings for sedimentation structures were not required. However, the operator was required to comply with the laws and regulations of the Pennsylvania Surface Mining Conservation and Reclamation Act.

The construction was done by digging two circular holes in the ground using a backhoe. The excavated material from the pond was dumped on the edge of the ponds to form the banks. Although the side slopes of the ponds were not stabilized by vegetation, the ponds functioned very well under both sampling conditions.

FIGURE 3. Overall View of Pond Number 1 (Two-Pond System). Inflow from the Pit is at the Lower Right.

FIGURE 4. Pond Number 2 - Primary Pond of Two-Pond System. Inflow from the Pit is through the Pipe at the Right.

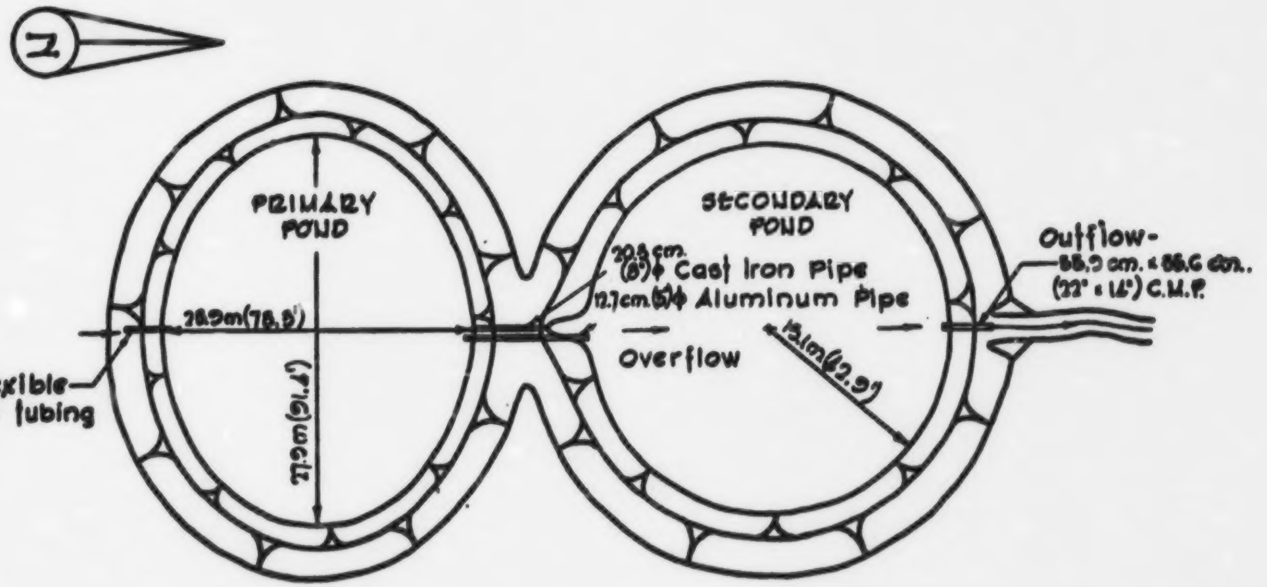

N
PRIMARY POND
SECONDARY POND
23.9m(78.5')
27.9m(91.7')
Inflow
12.7cm(5")ϕ flexible
plastic tubing
20.3 cm.
(8")ϕ Cast Iron Pipe
12.7cm.(5")ϕ Aluminum Pipe
Overflow
13.1m(42.9')
Outflow-
55.9 cm. x 35.6 cm.
(22" x 14") C.M.P.

FIGURE 5. As-Built Drawing of Pond Number 2

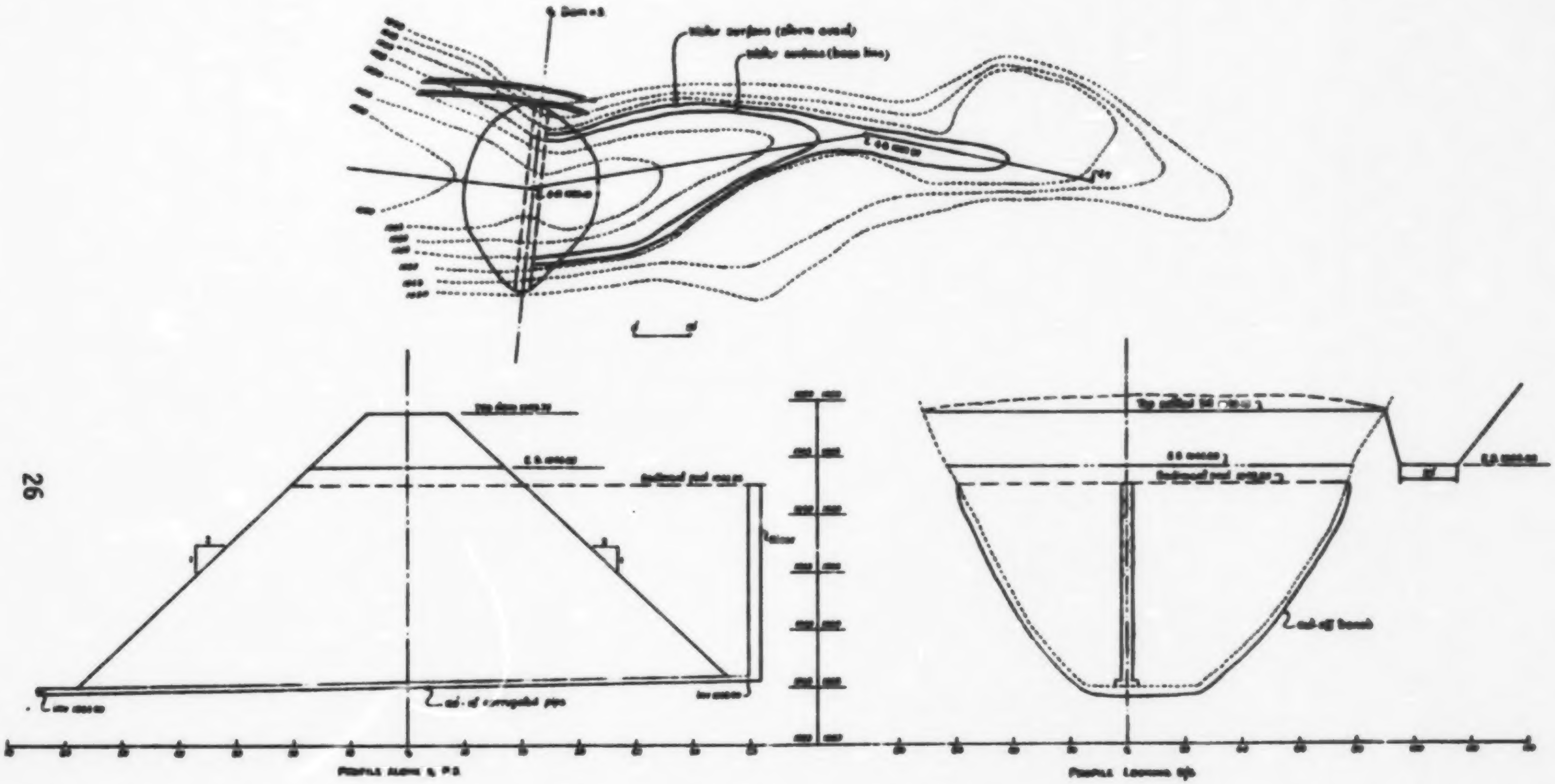
POND NUMBER 3

The sediments generated from this mining operation are controlled by two primary impoundments built across two small tributaries. The discharges from these two sediment control dams flow into the secondary impoundment built across the main stream approximately 200 m (700 ft) downstream. Under this study only the primary pond on one of the two tributaries was evaluated.

Figure 6 is a construction drawing of the pond. A 7.6 m (25 ft) high earth embankment was built with a 61.0 cm (24 in.) diameter perforated riser pipe and 45.7 cm (18 in.) diameter principal spillway. However, contrary to what is shown in the drawing, the top of the normal overflow riser was measured to be 1.0 m (3.3 ft) higher than the crest of the dam. The emergency spillway was constructed by cutting into the downstream side slopes, thereby making the slopes steeper and unstable. The capacity of the pond was observed to be greatly reduced due to sediment accumulation, and consequently the water had been regularly discharging through the emergency spillway. It was observed that gullies approximately 3 m (10 ft) deep (Figure 7) had been eroded into the emergency spillway channel, indicating that water had been frequently overflowing through the emergency spillway. An attempt was made by the mine operator to control the water overflowing through the emergency spillway by dumping a large log across the spillway (Figure 8). As seen from Figure 8, this log was undermined by approximately 0.6 m (2 ft). Heavy rains were prevalent in the area during the sampling period. The amount of rain in a nearby gaging station on the day of sampling was measured to be 3.53 cm (1.39 in.) and there was a flash flood warning for the area.

The capacity of the pond was reduced due to sediment accumulation, which at certain locations, was measured to be as much as 3.3 m (10.8 ft). The average depth of water in the pond was only 0.7 m (2.4 ft) and sediment had accumulated to above the water level at the upper end of the pond. However, lack of overall maintenance of the pond was the primary cause of the poor effluent quality. The vegetative cover on the embankment and side slopes was sparse and the perforations in the riser pipe or main barrel of the principal spillway were clogged.

In addition, the flow and velocity of flow into the pond was high. A whirlpool action was observed around the normal overflow riser pipe during the storm, which created a stirring action within the pond. This action resuspended



℄ Dam #3
Water surface (storm event)
Water surface (base line)

FIGURE 6. Construction Drawing of Pond Number 3

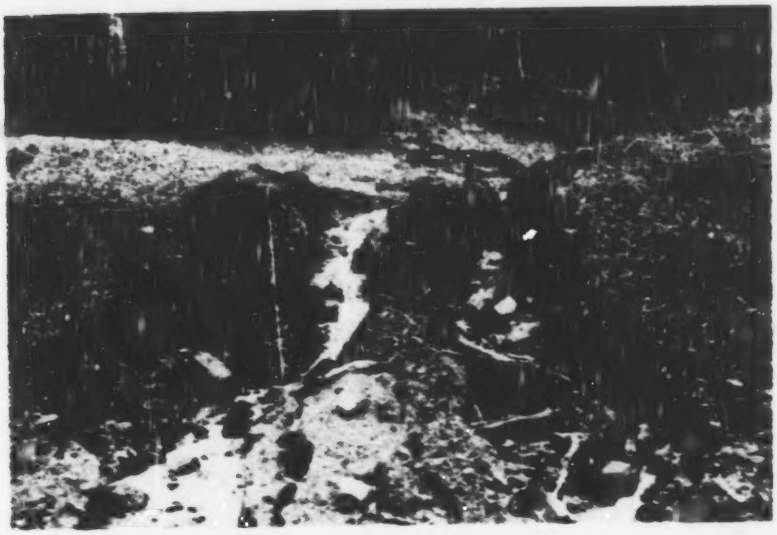


FIGURE 7. Deeply Eroded Channels as a Result of Water Flowing Frequently over the Emergency Spillway

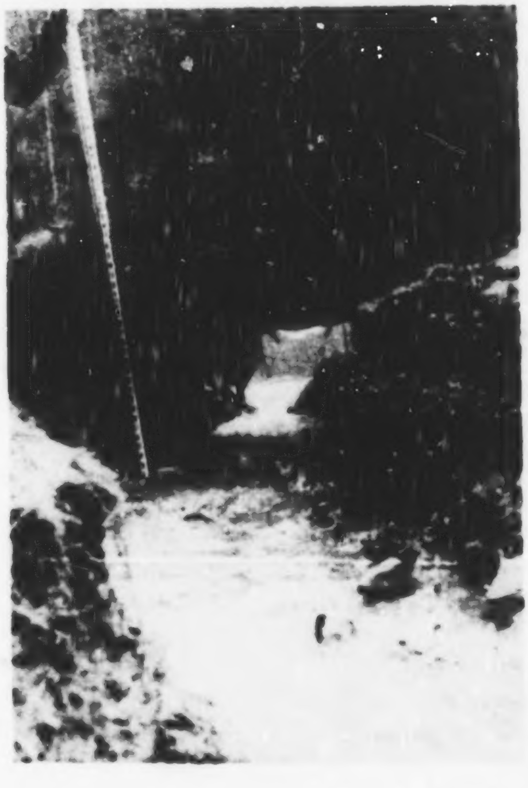


FIGURE 8. Undermining of the Log Across the Emergency Spillway

the deposited sediments and carried them into the outflow. Figure 9 shows an overall view of the pond and the observed whirlpool action.

POND NUMBER 4

This sediment control structure is also built across a stream channel and consists of an approximately 7.6 m (25 ft) high earth embankment with a 35.6 cm (14 in.) cast iron, perforated riser pipe and a 61.0 cm (24 in.) cast iron principal spillway pipe. Figure 10 is an overall view of the pond.

A large amount of overburden had been generated from the mountain top removal mining activity. This overburden was placed in the adjacent natural depressions and is generally referred to as hollow fill. Erosion from the slopes of the hollow fills was heavy and was the main source of sediment to the pond.

Conventionally, in the design of the riser type of outflow from sediment control structures, the size of the riser pipe is larger than the spillway pipe. The approved design drawings reflected this relationship, but the overflow was constructed differently as shown in Figure 11. The principal spillway pipe was observed to be a 61.0 cm (24 in.) diameter cast iron pipe as opposed to the designed 35.6 cm (14 in.) diameter steel pipe. Also, the vertical riser pipe was a 35.6 cm (14 in.) diameter cast iron pipe as opposed to the designed 50.8 cm (20 in.) diameter steel pipe. The emergency spillway was constructed by cutting into the downstream side slope thereby making the slope steeper and unstable. The pond embankment slopes were well-vegetated and stabilized.

The amount of rain for the day of sampling was measured to be 6.73 cm (2.65 in.) at a nearby gaging station. This pond was also relatively ineffective in removing suspended solids during the measured storm event. This was probably due to the high inflow rate and relatively small pond surface area. This pond had the highest flow to surface area ratio of any pond sampled during the rainfall event. Another factor which contributed to the low quality effluent was that a large amount of sediment had accumulated in the pond. The water depth averaged less than 0.7 m (2.5 ft) near the riser pipe.

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FIGURE 9. Overall View of Pond Number 3 and Observed Whirlpool Action Within the Pond

FIGURE 10. Overall View of Pond Number 4

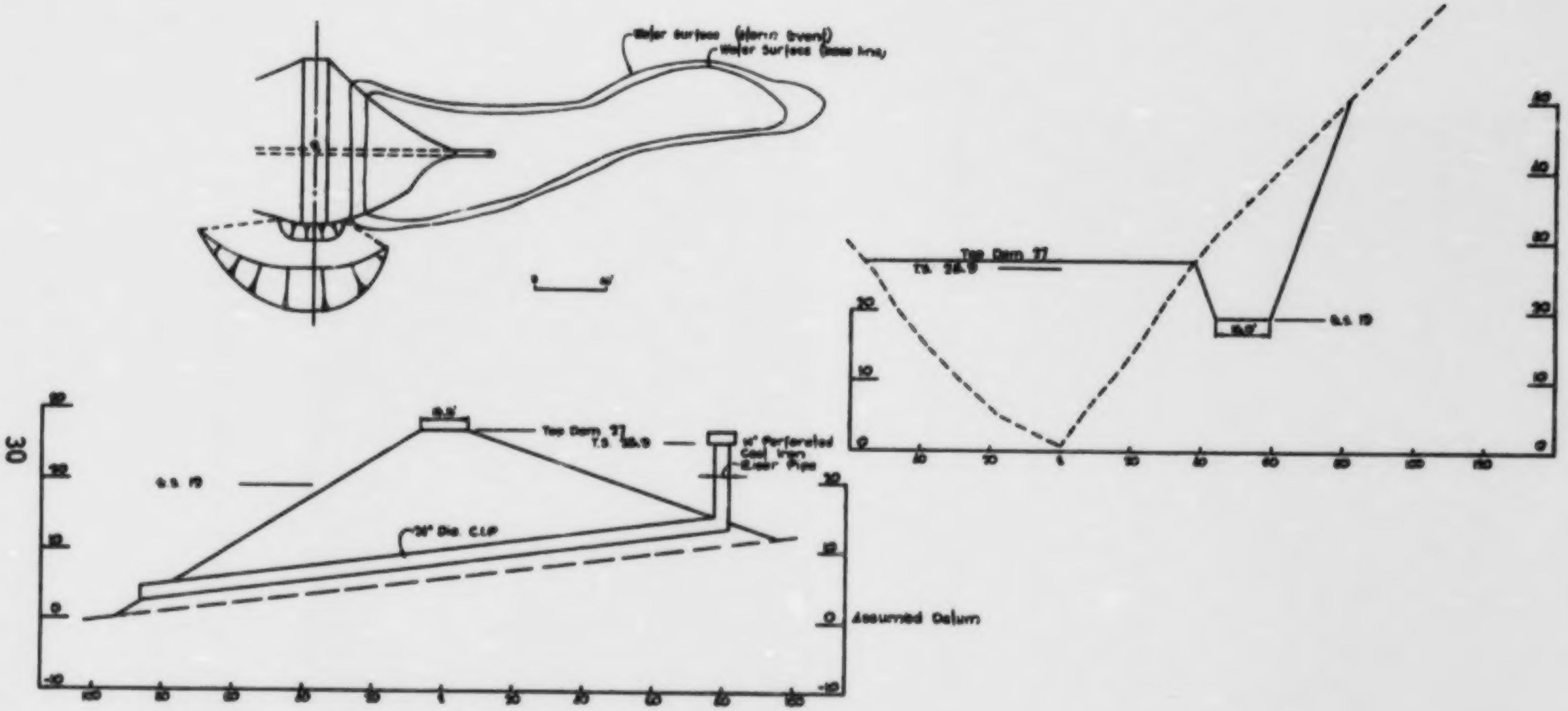
Water Surface (Storm Event)
Water Surface (Base line)
0
40'
Top Dam 37
T.S. 36.9
G.S. 19
Top Dam 37
T.S. 35.9
G.S. 19
18" Perforated
Cast Iron
Riser Pipe
24" Dia. C.I.P
Assumed Datum

FIGURE 11. As-Built Drawing of Pond Number 4

POND NUMBER 5

The provision of any sediment control structure in western Kentucky is voluntary on the part of mine operators, as long as the State discharge requirements are met. Designs and drawings for this pond, therefore, were not prepared. It was built by piling overburden from the mine onto a cleared ground surface to form a containment area. There was no provision for an emergency spillway. The outflow from the pond was through a 30.5 cm (12 in.) diameter corrugated metal pipe which discharged into the natural waterway. The pond can be classified as a dugout type pond.

In this area mining operation, surface runoff from most of the disturbed areas is collected in the pit, from where it is pumped into the inflow channel to the sediment pond. This inflow channel flows through a metal culvert pipe under a haul road at the upstream end of the pond. The culvert pipe had silted-up and was buried under the sediments. Consequently, water was flowing over the unstabilized haul road and then into the pond. Maintenance and construction vehicles continued to traverse the haul road, thus stirring up sediment which was subsequently washed into the pond.

The sediment pond was also comparatively small and very shallow. Figure 12 shows the outline of the shape and size of the pond and Figure 13 is an overall view of the pond. Very little freeboard was provided to accommodate the amount of water being pumped from the pit. The water level during the storm event was only 20.3 cm (8 in.) below the top of the containment berm. In fact, the containment berm was breached toward the end of the rainfall event sampling period as shown in Figure 14. Compaction of the berms was inadequate, and they were not vegetated. Consequently, erosion of the berm caused its failure. This erosion was partly responsible for the low measured removal efficiency during the storm event.

In general, the design, construction, operation, and maintenance of this pond was inadequate, resulting in the measured low efficiency and subsequent failure of the containment berm.

POND NUMBER 6

Ponds of this size and magnitude are seldom built for the purpose of sediment control only. In addition to sediment control, this pond was also built to serve as a recreational

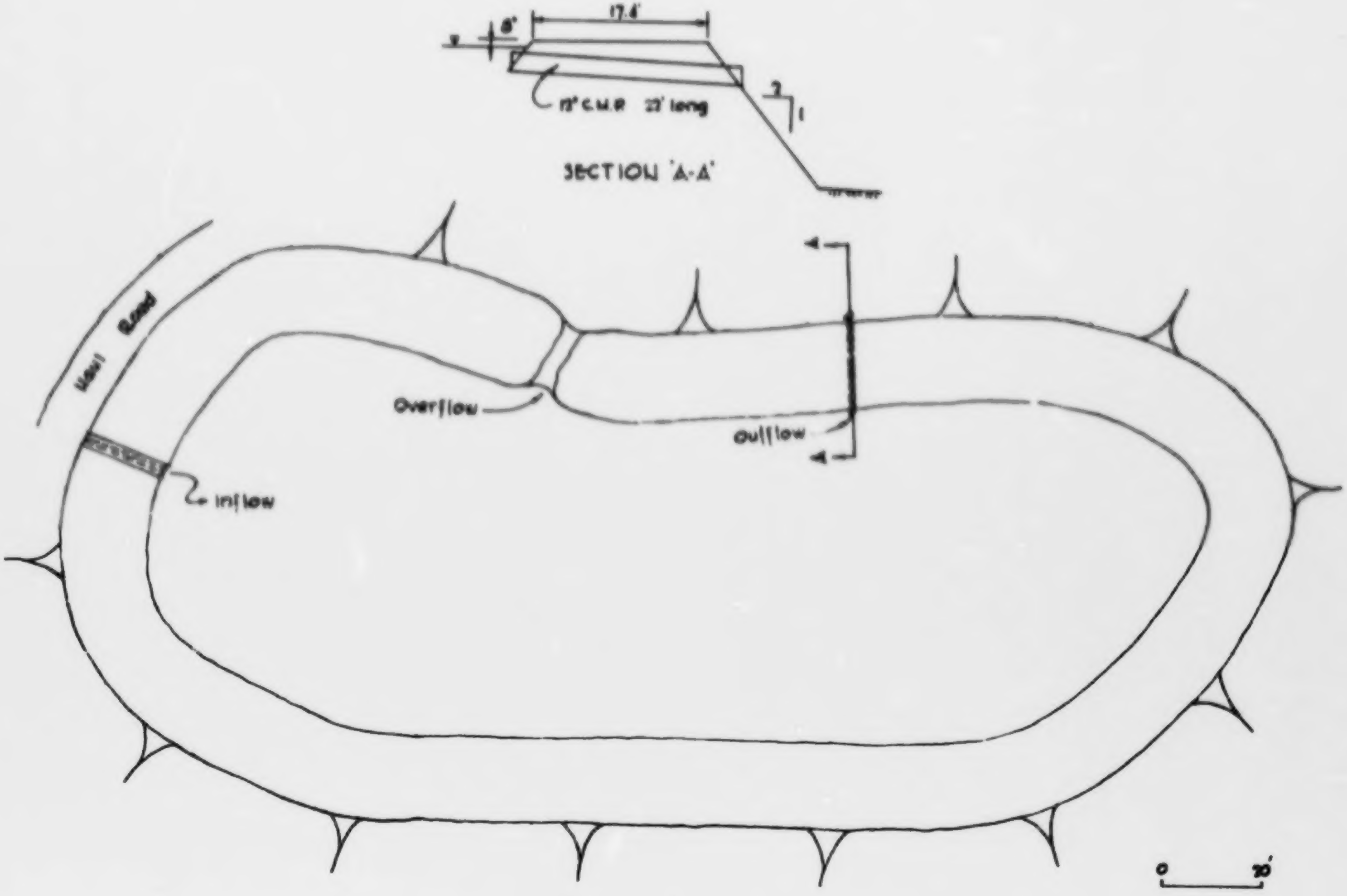
17.4'
6"
12" C.M.P. 22' long
2
1
SECTION 'A-A'
Haul Road
Overflow
outflow
inflow
0
20'

FIGURE 12. As-Built Drawing of Pond Number 5

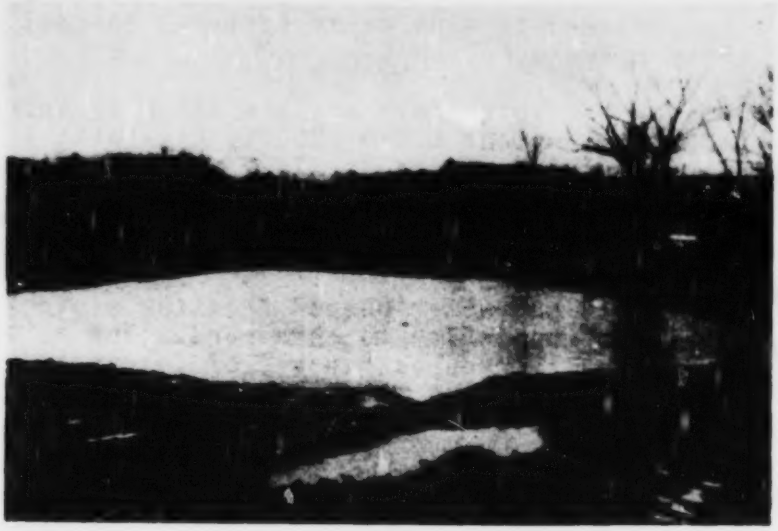

FIGURE 13. Overall View of Pond Number 5. Inflow is at the Top, Center.

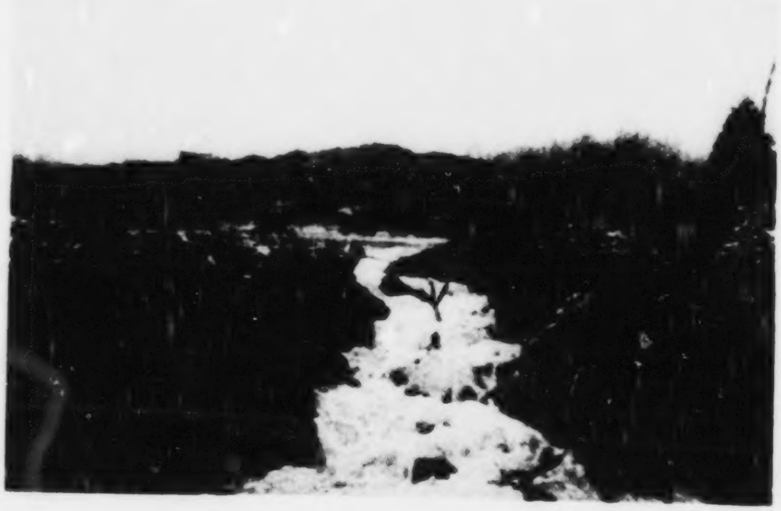

FIGURE 14. Water Escaping from the Eroded Portion of the Sediment Pond

lake for the nearby homeowners after the mining activity is terminated. The reason for selecting this site for evaluation was that this was a well-built and well-engineered structure as compared to many other sediment control structures in western Kentucky.

The earth embankment which impounds the water is approximately 183 m (600 ft) long and 6.1 m (20 ft) high with a 30.5 cm (12 in.) diameter trickle tube outflow. The construction drawing of the structure is shown in Figure 15 and an overall view of the pond is shown in Figure 16. The emergency spillway consists of a bare earth chute with no vegetation.

Both surface runoff and water pumped from the mining pit area contribute to the inflow to this pond. The velocity at the inflow was greatly reduced because of debris and trees which had been felled across the inflow channel (Figure 17), resulting in the deposition of sediment before it reached the pond.

Even though the pond was built oversize, the overflow pipe through the embankment was undersized. This resulted in clogging of the overflow pipe. Consequently, water continually flowed through the emergency spillway. Since there was inadequate protection against erosion downstream from the emergency spillway, severe downstream off-site damage resulted as seen in Figure 18.

POND NUMBER 7

Figure 19 shows an overall view of the pond looking toward the dam. Figure 20 is the detailed design drawing of this sediment control structure. Contrary to the dimensions shown in the drawing, an earth dam having a top width of 9.73 m (31.9 ft) and a height of approximately 6.1 m (20 ft) was built. The outflow structure consisted of a 91.4 cm (36 in.) perforated steel riser pipe and a 61.0 cm (24 in.) steel principal spillway pipe. The emergency spillway was built of a grassed channel instead of a riprap channel as shown in the drawings. However, the surface area of the pond was essentially the same as shown on the drawings.

There was mining activity on both sides of the valley across which this embankment was built. A portion of the flow into this pond was from another small sediment pond just upstream from this one. The upstream pond trapped sediments generated on one side of the valley. There was evidence of severe erosion of the slopes near the mining activity due to the high velocity of the surface runoff from the steep slopes.

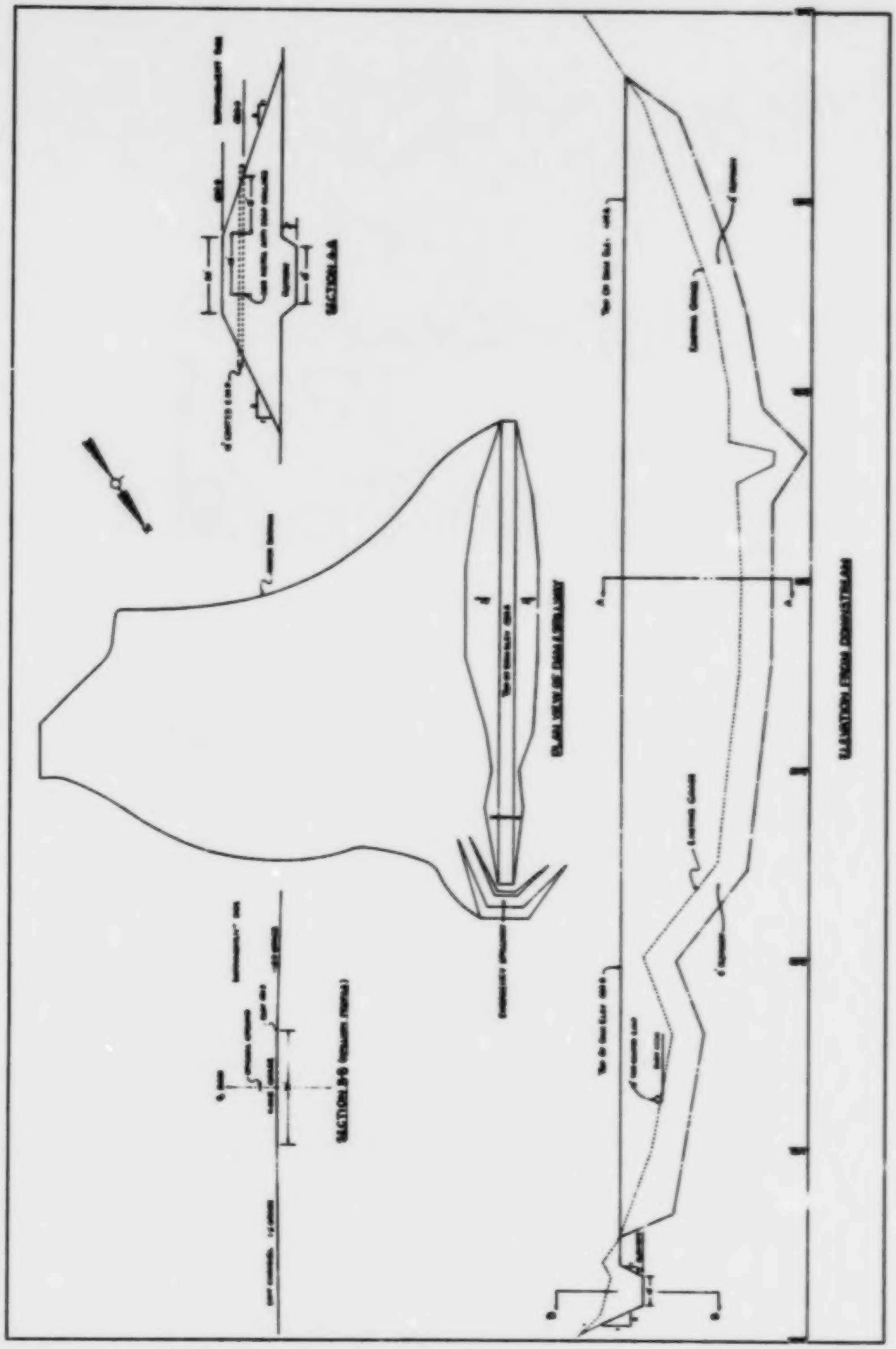
SECTION A-A
SECTION B-B
PLAN VIEW OF DAM & SPILLWAY
ELEVATION FROM DOWNSTREAM

FIGURE 15. Construction Drawing of Pond Number 6

FIGURE 16. Overall View of Pond Number 6

FIGURE 17. Inlet Channel to the Pond with Debris Across It

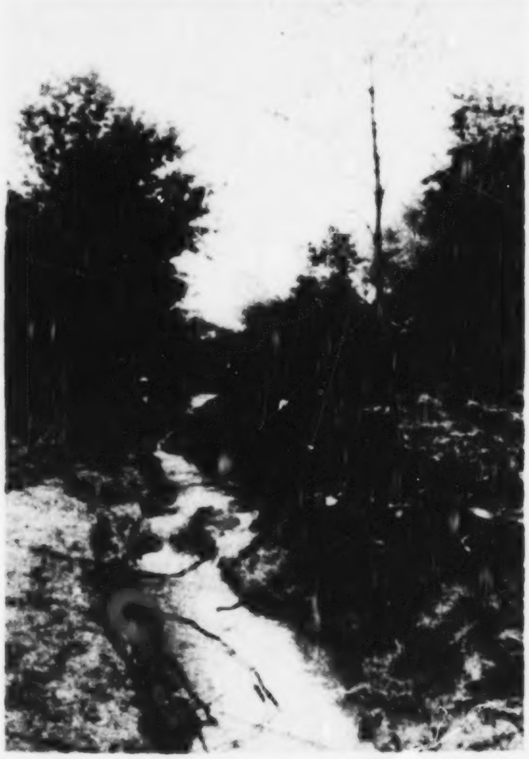

FIGURE 18. Erosion of Road Caused by Overflow Through the Emergency Spillway (Pond No. 6)

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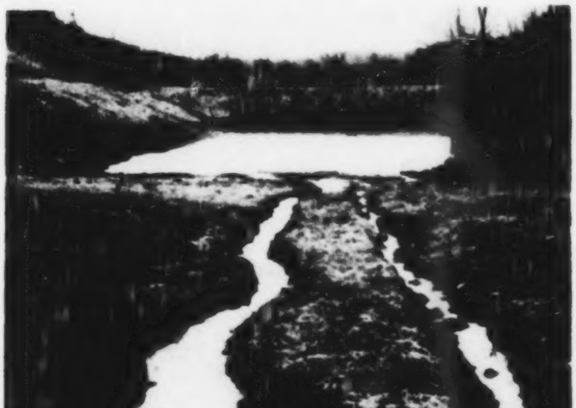
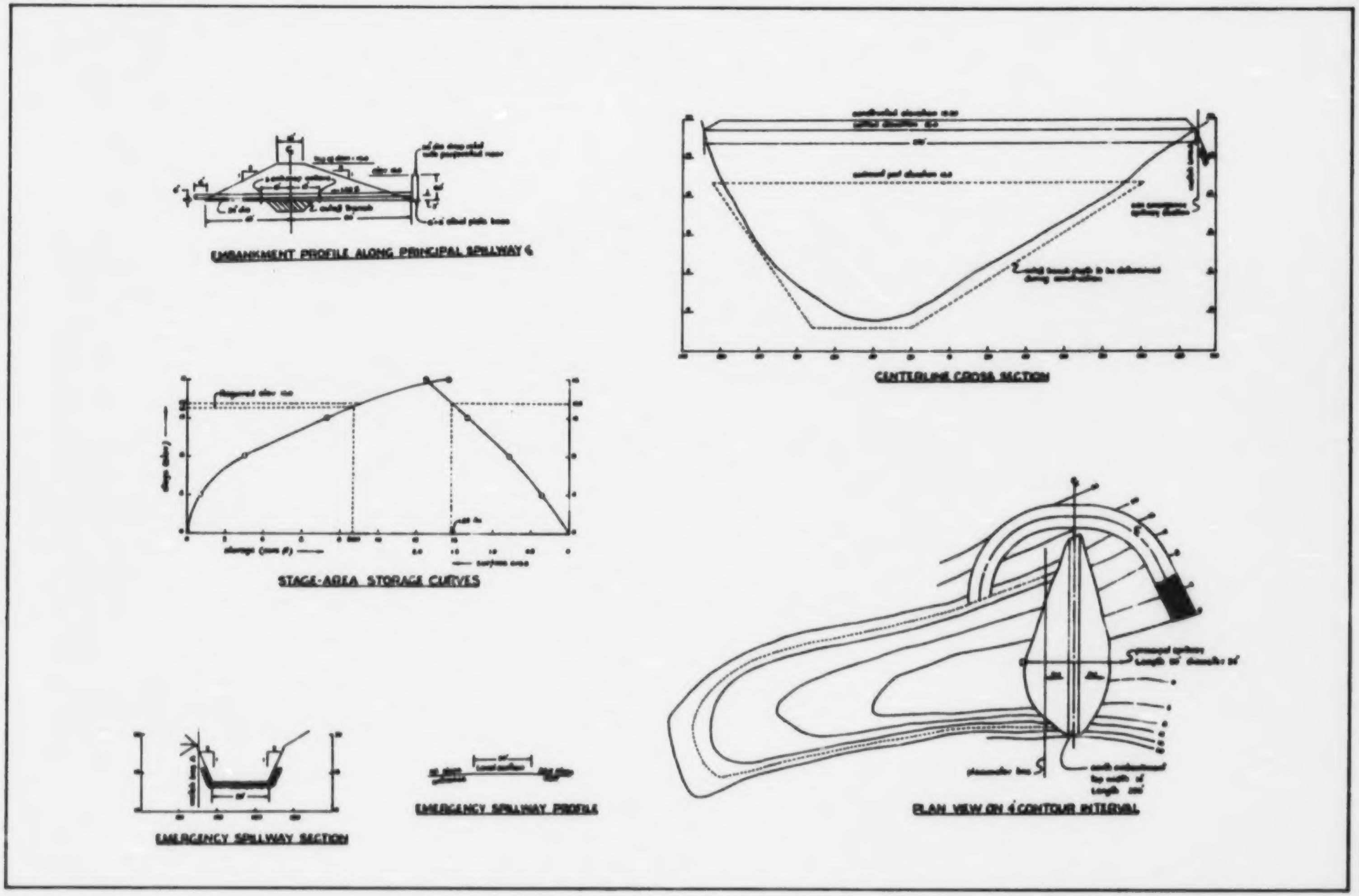


FIGURE 19. Overall View of Pond Number 7



EMBANKMENT PROFILE ALONG PRINCIPAL SPILLWAY ℄
CENTERLINE CROSS SECTION
STAGE-AREA STORAGE CURVES
storage (acre ft)
surface area
EMERGENCY SPILLWAY SECTION
EMERGENCY SPILLWAY PROFILE
PLAN VIEW ON 4' CONTOUR INTERVAL

FIGURE 20. Construction Drawing of Pond Number 7

The pond had a negative removal efficiency, i.e., a higher suspended solids concentration in the effluent than in the influent toward the end of the baseline sampling period. This was due to the presence of algae in the outflow samples. The algae were present on the pond surface and attached to the riser pipe. Toward the end of the sampling period, some of these algae broke loose and entered the pond outflow. On the other hand, the algae deposits around the perforated riser pipe acted as a filter, retaining most of the suspended solids in the pond and thus resulting in a cleaner discharge through the outflow during the measured rainfall event. The rain during this period of sampling was intermittent with periods of high intensity rain. The total amount of rain recorded was 2.21 cm (0.87 in.). During the rainfall event the relatively high inflow to the pond was observed to cause short circuiting of the flow through the pond. The overall performance of the pond was good.

POND NUMBER 8

The purpose of this pond is twofold: to control sediments generated by surface mining activity upstream, and to supply water for an adjacent deep mine. This is a relatively well-built pond consisting of an earth embankment approximately 6.1 m (20 ft) high, with a 0.92 m (3 ft) square steel drop inlet and a 76.2 cm (30 in.) diameter steel spillway pipe. The emergency spillway consists of an expensively built concrete channel. The embankment and its side slopes were well-vegetated but the side slopes of the pond itself showed signs of degradation. Sloughing of the slopes into the impoundment was observed. The construction drawing of the pond is presented in Figure 21. Figure 22 is an overall view of the pond.

The pond was observed to be ineffective in removing suspended solids during the baseline sampling period. An average efficiency of -128 percent during the six and one-half hour measured baseline reflects some unusual operating conditions during that specific time. The location of the pump intake for the deep mine was very close to the riser pipe which is the outflow for the pond (Figure 23). The action of the pump resulted in a local disturbance within the pond, resuspending the deposited sediments which were subsequently carried out the outflow.

Although the suspended solids content of the influent during the storm event was relatively high, the effluent was cleaner than during the baseline conditions and met all State and Federal discharge criteria. The design and construction of

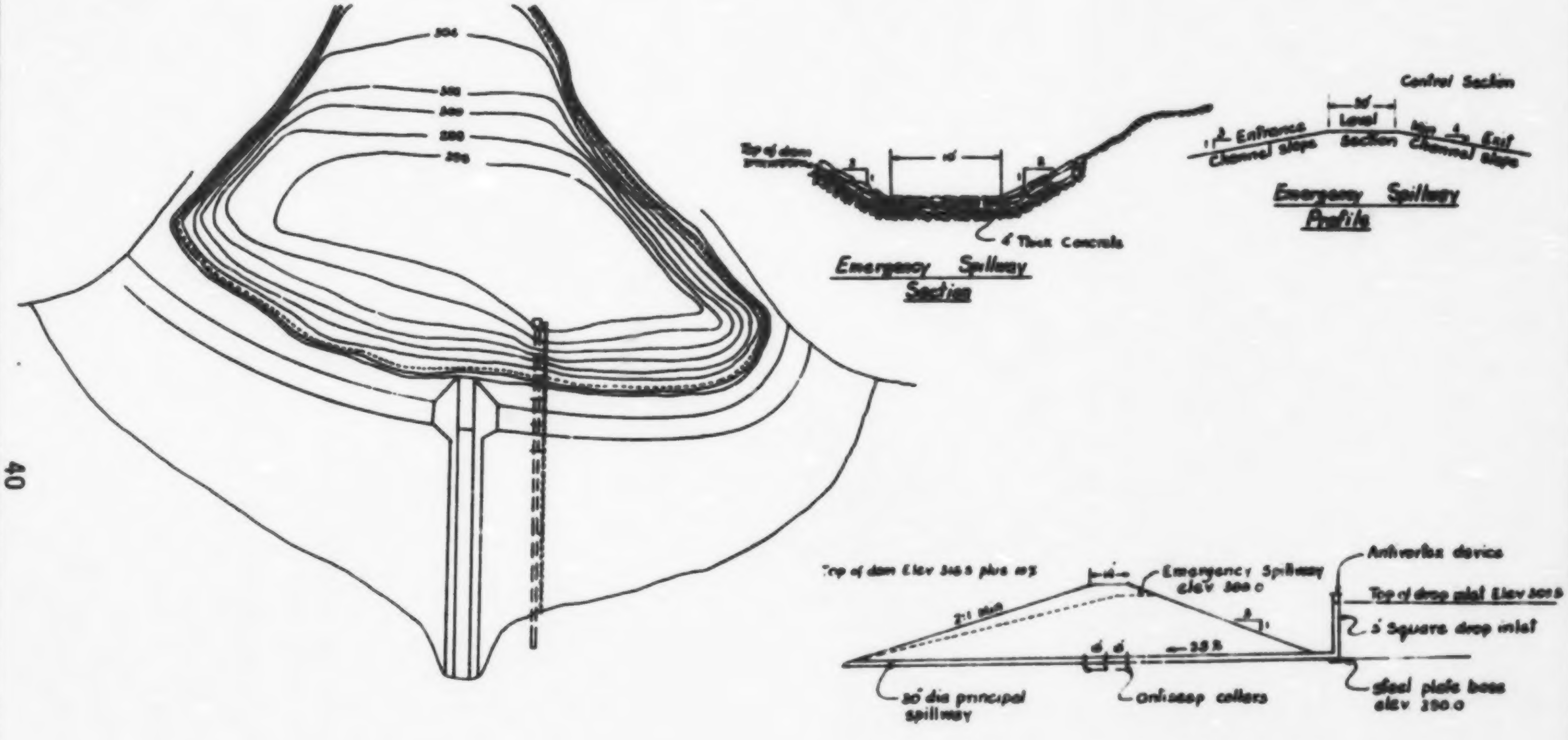

304
300
298
296
Top of dam
10'
4" Thick Concrete
Emergency Spillway
Section
Control Section
30'
Level
Section
Entrance
Channel slope
Exit
Channel slope
Emergency Spillway
Profile
Top of dam Elev 306.5 plus 10%
2:1 slope
Emergency Spillway
elev 300.0
Antivortex device
Top of drop inlet Elev 301.5
5' Square drop inlet
35 ft
20" dia principal
spillway
antiseep collars
Steel plate base
elev 290.0

FIGURE 21. Construction Drawing of Pond Number 8

FIGURE 22. Overall View of Pond Number 8 Showing the Pumping Arrangements for the Deep Mine and Eroding Side Slopes

the pond was adequate as far as removal of suspended solids was concerned, but little consideration was given to the downstream effects of the outflow from the principal and emergency spillways. The discharge water flows directly onto an unstabilized dirt road (Figure 24). The water then flows along the dirt road for some distance until it finally flows across the road and discharges into the natural watercourse (right-hand side of Figure 24). In the process, the road is eroded and the sediments are carried into the natural waterway.

POND NUMBER 9

This is a combination of dugout and embankment type sediment pond. The capacity of this pond was increased by hollowing out the natural stream channel across which the embankment was built. An embankment approximately 2.1 m (7 ft) high was constructed with three 50.8 cm (20 in.) diameter steel outflow pipes under a grouted riprap emergency spillway. Figure 25 shows the construction drawing of this pond. Figure 26 is an overall view of the pond, looking toward the dam.

FIGURE 23. Close View of Pond Outflow Riser Pipe, Access Deck, and Pumping Unit for Deep Mine

FIGURE 24. Outflow from the Pipe (Left) onto the Dirt Road which Eventually Flows into the Natural Waterway (Right-Hand Side)

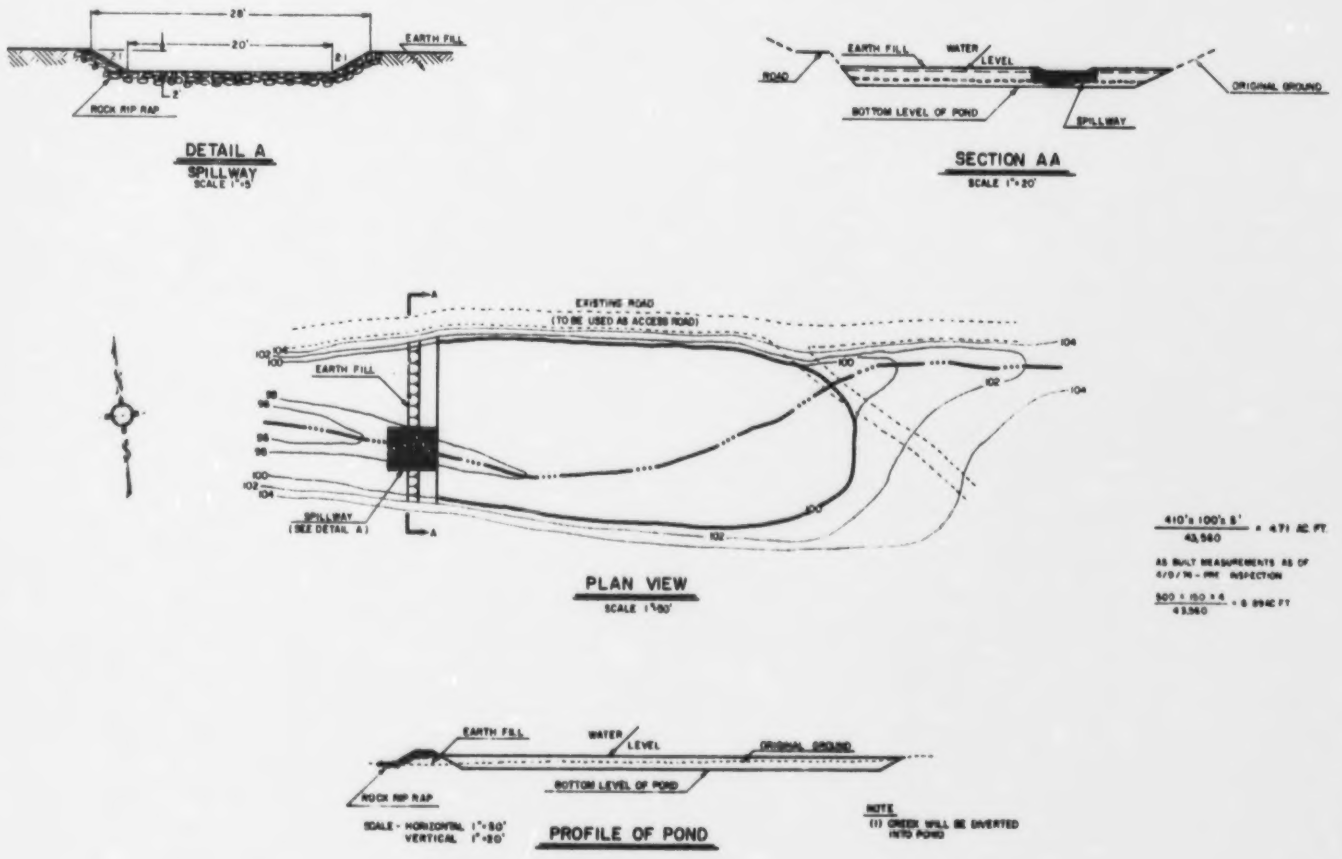

28'
20'
EARTH FILL
2:1
2'
ROCK RIP RAP
DETAIL A
SPILLWAY
SCALE 1"=5'
ROAD
EARTH FILL
WATER
LEVEL
BOTTOM LEVEL OF POND
SPILLWAY
ORIGINAL GROUND
SECTION AA
SCALE 1"=20'
EXISTING ROAD
(TO BE USED AS ACCESS ROAD)
A
A
EARTH FILL
SPILLWAY
(SEE DETAIL A)
102
104
100
98
96
98
96
100
102
104
100
102
104
104
PLAN VIEW
SCALE 1"=50'
410' x 100' x 5' / 43,560 = 4.71 AC FT
AS BUILT MEASUREMENTS AS OF 4/9/76 - PRE INSPECTION
500 x 150 x 4 / 43,560 = 6.89AC FT
EARTH FILL
WATER
LEVEL
ORIGINAL GROUND
ROCK RIP RAP
BOTTOM LEVEL OF POND
SCALE - HORIZONTAL 1"=50'
VERTICAL 1"=20'
PROFILE OF POND
NOTE
(1) CREEK WILL BE DIVERTED INTO POND

FIGURE 25. Construction Drawing of Pond Number 9

FIGURE 26. Overall View of Pond Number 9, Looking Toward the Dam

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FIGURE 27. Sediment Deposits at Upper End of Pond

The side slopes of the pond and the embankment itself were well-vegetated. Normal overflow occurs through the three steel pipes below the emergency spillway. These pipes discharge their water on the downstream face of the emergency spillway. Thus, streambed erosion downstream of the dam due to normal discharge was kept to a minimum. Inflow to the pond is from the main channel and a small seep which enters the pond from its northern side. However, the main stream contributes over 97 percent of the inflow to the pond.

The pond was quite effective in removing suspended solids during the measured baseline conditions, but was less effective during the rainfall event. In the time period between the initial baseline sampling and the sampling during the rainfall event, the pond continued to rapidly fill with sediment. By the time the pond was sampled during the rainfall event a few months later, the upper one-half of the pond was essentially completely filled with sediment, i.e., the sediment has accumulated to within a few centimeters of the water surface as seen in Figure 27. This rapid accumulation of sediment was found to be due to logging in the watershed which preceded the mining operation. The haul road for the logging trucks paralleled the stream and, for at least one mile of its length, ran right in the streambed itself. Lumber trucks were observed to be traversing this road/streambed at the rate of approximately one per hour while field personnel were at the site in the spring of 1975. During this period of lumbering activity, the strip mining operation was observed to contribute very little sediment directly to the pond. Thus, the rapid filling of the pond was due mainly to the use of the streambed and floodplain as a haul road by the lumber trucks.

SECTION VII

OBSERVATIONS AND ANALYSES OF FIELD DATA

As described earlier, each of the nine ponds was sampled under two different conditions, generally referred to as a baseline (nonstorm) condition and during a rainfall event. Tables 4 and 5 present the results of the sampling program for these two conditions. The objective was to obtain an indication of how each pond responded under two different operating conditions.

During most of the sampling periods the variation in the rate of inflow to the pond over the period of sampling was minor. The pond removal efficiencies and detention times in such cases were calculated using the average flow rate. When a wider flow range occurred, detention times and efficiencies were calculated for the minimum and maximum flow rates.

The percentage of solids actually removed by each pond was determined by using the equation derived for a simple mass balance for a conventional containment basin given as Equation 1 in Section V. The solids concentrations of the influent and effluent used in Equation 1 were obtained from the inflow and outflow water quality samples taken during the course of the field surveys. The average influent and effluent suspended solids concentration during the period of sampling was used in this equation to solve for the actual removal efficiency.

The theoretical efficiency was determined using Stokes' Law (see Appendix B). Using the measured surface area and inflow to the pond, the critical settling velocity was computed as:

$$V_C = \frac{Q}{A} \qquad (2)$$

where: V_C = critical settling velocity

Q = pond inflow

A = pond area

Table 4. RESULTS OF POND SAMPLING DURING THE BASELINE CONDITION

Pond no.	Flow average/range (m^3/sec)	Computed detention time (hr)	Sampling Period (hr)	No. of Samples	Average suspended solids con. (mg/l)		Actual removal efficiency (%)	Theoretical removal efficiency (%)
					Influent	Effluent		
1	0.014	49.4	2	8	<5	<5	-	99.0
2	0.015-0.006	31.9-75.3	2	8	1412	12	99.2	98-99
3	0.028	12.9	2	8	1876	200	89.3	90.0
4	0.020	10.5	2	8	5181	128	97.5	95.0
5	0.017	15.2	2	8	1616	100	93.8	95.0
6	0.064	213.0	2	8	954	23	97.6	98.0
7	0.011	17.3	2	8	13	15	-16.0	98.0
8	0.034	72.2	6¼	7	43	97	-128.1	93.0
9	0.122	8.0	2	8	324	31	90.4	94.0

Table 5 . RESULTS OF POND SAMPLING DURING RAINFALL CONDITIONS

Pond no.	Flow average/range (m^3/sec)	Computed detention time (hr)	Sampling Period (hr)	No. of samples	Average suspended solids con. (mg/l)		Actual removal efficiency (%)	Theoretical removal efficiency (%)
					Influent	Effluent		
1	0.021	31.9	2	8	474	196	58.8	95.0
2	0.028	-	2	8	239	17	92.8	88.0
3	0.149	7.8	4	8	21970	11539	48.0	83.0
4	0.133	4.4	4	16	9643	6198	36.4	84.0
5	0.060	5.2	5	9	668	275	58.8	91.0
6	0.042	325.0	26	8	868	35	95.9	99.0
7	0.012-0.093	20.8-2.7	16	9	765	66	91.3	83.0-67.0
8	0.013	184.4	5½	8	363	28	92.3	97.0
9	0.056-0.110	5.7	7	10	412	193	53.1	99.0

This computed critical settling velocity, along with the measured specific gravity of the incoming suspended sediment was then used in Stokes' Law to determine the diameter of the smallest particle which would theoretically settle at that critical settling velocity. The formula used was:

$$V_C = \frac{g}{18\nu}(S_s - 1)D^2 \qquad (3)$$

where: V_C = critical settling velocity, cm/sec

g = acceleration due to gravity = 981 cm/sec^2

D = diameter of a spherical particle, cm

S_s = specific gravity of the particle

ν = kinematic viscosity of water, cm^2/sec

The kinematic viscosity of water was determined based on the measured temperature of the inflow to the pond.

This calculated particle diameter was compared to the measured grain size distribution of the incoming suspended sediment (Appendix C) and the percent of particles finer than this size was found. This percent finer was the theoretical removal efficiency of the pond.

The theoretical effect of short circuiting on the efficiency was also computed for some of the ponds where this effect was thought to be a problem. However, theoretically, short circuiting was never found to cause a significant difference in the ideal settling for any of the ponds studied.

Computations of sediment loading and accumulation for the two sampling periods and during the life of pond were also made. These computations were performed in order to get an estimate of the amount of sediment generated in the watershed over the life of the pond and the amount entering the pond during the sampling periods. The results of these calculations are presented in Table 6. The sediment accumulation over the life of the pond was computed by assuming that the settled sediment had an in-place water content of 50 percent. Using this value and knowing the approximate life of the pond, the total weight of sediment accumulated over the life of the pond was calculated by utilizing the data on volume and specific gravity of the settled sediment collected during the field surveys. The life of the pond was determined from State approval and inspection records and through discussions with the mine foreman. Sediment loading during the sampling periods was calculated through a simple mass balance between the suspended solids concentration in the inflow versus the suspended solids concentration in the outflow, again using the flow data measured during the course of the field surveys.

Table 6. ESTIMATED SOLIDS ACCUMULATION

Pond no.	During baseline			During storm event			During life of pond		
	Period (hrs)	Metric ton/hr	m^3	Period (hrs)	Metric ton/hr	m^3	Period (mo)	Metric ton/day	m^3
1	2	neg.	neg.	2.0	0.02	0.02	20	1.00	2.29
2	2	0.05	0.04	-	-	-	-	-	-
3	2	0.17	0.13	4.0	5.62	8.29	12	8.44	1125
4	2	0.36	0.28	4.0	1.63	2.54	9	5.99	624
5	2	0.09	0.11	5.0	0.08	0.26	-	-	-
6	2	0.21	0.17	4.0	0.07	0.12	-	-	-
7	-	-	-	4.0	0.11	0.16	24	0.57	161
8	-	-	-	5.5	0.02	0.03	10	4.81	534
9	2	0.13	0.10	7.0	0.06	0.16	6	14.88	1035

Table 7 gives range of the observed suspended solids concentrations, turbidity, and pH of the measured pond effluents during the two sampling periods and comparisons of these parameters with the Federal and various State standards for effluents from surface mining operations. A discussion of the Federal and State standards has been presented in Section IV of this report.

Table 7. COMPARISON OF OBSERVED EFFLUENT QUALITY WITH VARIOUS EFFLUENT STANDARDS

	Suspended solids (mg/1)						Turbidity (JTU)						pH			
	Baseline			Storm event			Baseline			Storm event			Baseline		Storm event	
	Low	Mean	High	Low	Mean	High	Low	Mean	High	Low	Mean	High	Low	High	Low	High
Federal*	30	-	100	30	-	100	-	-	-	-	-	-	6.0	9.0	6.0	9.0
State:*																
Pennsylvania[+]	-	-	60	-	-	60	-	-	-	-	-	-	6.0	9.0	6.0	9.0
West Virginia	-	-	-	-	-	-	-	-	200	-	-	1000	5.5	9.0	5.5	9.0
Kentucky	-	-	-	-	-	-	-	-	150	-	-	1000	6.0	9.0	6.0	9.0
Pond:																
#1	1	3	4	152	196	235	3	5	7	120	138	160	7.3	7.5	7.4	7.5
#2	7	12	18	13	17	20	5	9	15	12	16	21	7.1	7.4	7.3	7.4
#3	121	200	429	5160	11539	41840	100	148	300	1000+	-	-	6.8	7.0	5.7	5.9
#4	24	128	412	3408	6198	8437	19	75	270	1000+	-	-	7.2	7.6	6.6	6.8
#5	54	100	158	110	308	521	50	91	160	130	273	380	6.6	6.7	6.1	6.5
#6	3	23	44	20	35	43	25	37	45	24	42	50	6.2	6.5	6.4	6.6
#7	4	15	39	11	66	340	2	3	4	10	34	85	7.1	7.3	5.9	8.1
#8	80	97	113	16	28	50	90	115	130	25	32	50	5.1	7.0	6.4	6.8
#9	14	31	52	107	193	341	10	15	26	170	207	260	6.6	6.7	6.5	6.8

---

*For detailed Federal and State effluent standards, see Table 2.

[+] Pennsylvania has no minimal numerical limit on suspended solids or turbidity. However, for the evaluation and certification of NPDES applications, the State follows guidelines for suspended solids which indicate that discharges should average no more than 30 mg/1 monthly with maximum discharges not to exceed 60 mg/1.

SECTION VIII

DISCUSSION

REMOVAL EFFICIENCY

It is evident from Table 4 that most of the sampled ponds have high suspended solids removal efficiencies during the measured baseline or non-storm conditions. Ponds 7 and 8, which showed negative efficiencies because of some abnormal and unusual conditions prevailing at the time of sampling, are the exceptions. In Pond 7, algae were present on the pond surface. The algae broke loose during the sampling period and entered the outflow. In Pond 8, disturbances due to the action of an intake pump for a deep mine located close to the riser pipe caused resuspension of settled sediments, which were carried into the outflow. The removal efficiencies of the remaining ponds, operating under normal conditions, were measured to be approximately 90 percent or greater during the baseline conditions.

As seen from Table 5, the efficiencies during the storm event were generally much lower than during the baseline conditions. In particular, Ponds 3 and 4, the two ponds in eastern Kentucky, gave a poor performance during high flows. The poor performance of Pond 4 was due to the high inflow velocity to the pond and short circuiting within the pond, resulting in resuspension of settled sediments. This could have been controlled by the construction of simple velocity checks at the inflow to the pond. In Pond 3, the poor construction and maintenance of the pond caused severe erosion of the emergency spillway channel, resulting in the poor pond performance.

The effectiveness of all ponds could have been greatly improved if better operation and maintenance procedures were instituted. Some of the parameters which led to overall poorer performance than expected included:

(1) Ponds which had been in existence for a long period of time had almost exhausted their capacity

to store sediment. In many cases the deposited sediments were resuspended due to high inflow velocities or other disturbances and were subsequently carried out the outflow. This highlights the need for timely cleaning of the ponds.

(2) Many principal spillway pipes were clogged and needed cleaning. As a consequence, water was escaping through the emergency spillway or eroding other portions of the containment berms. Thus, inspection of the pond should be performed by mine personnel on a daily basis so that any required maintenance can be performed immediately.

(3) Erosion of poorly vegetated and steep pond side slopes contributed to poor effluent water quality.

(4) During high flows in the pond, sediments were carried through the perforations in the outflow riser pipe due to less detention time being available for the particles to settle in the pond.

Only Pond 2 (an off-channel, dugout pond) and Pond 6 (the pond with the greatest surface area) showed high suspended solids removal efficiencies under both sampling conditions. It may not be physically possible to construct ponds with a large surface area such as Pond 6 at most surface mining operations. However, where slopes are steep, multiple ponds may provide an effective alternative to large ponds.

Off-channel, dugout type ponds appear to be highly effective because the surface runoff from the mining area does not flow directly into the pond. Instead, it first flows into the pit area where some settling of the suspended load occurs. From there it is pumped into the sediment pond. Thus, the inflow to the sediment pond can be more precisely controlled and results in a higher final effluent quality. These ponds are most commonly constructed to control sediments from area surface mining operations. In actual practice, the pit area in area surface mining operations functions as a primary settling basin and thus helps to increase the final effluent quality. Because of its high efficiency and low maintenance requirements, the off-channel, dugout type sedimentation pond appears to be the most reliable solution to the problem of sediment control from surface mining activity. However, construction of an off-channel, dugout type of pond may not always be feasible because of geographical and physical constraints.

One problem which may be encountered with off-channel type ponds is that it may not be able to site a single pond so as to collect all the runoff from the entire disturbed area. This would necessitate the building of more than one sediment control structure so that sediment from the entire disturbed area can be controlled.

Theoretical efficiency as predicted by Stokes' Law was essentially the same as the actual efficiency under baseline conditions for the ponds which operated under normal conditions. During the rainfall event, however, there was generally little or no correlation between the theoretical and actual efficiencies as seen in Table 5. The predicted efficiencies were found to be much higher than the actual efficiencies in most cases. Many deficiencies are inherent in the use of Ideal Settling Theory, i.e., Stokes' Law in predicting the efficiency of irregularly shaped sediment ponds. The theory does not adequately account for the local disturbances within the pond. The pond removal efficiency is extremely sensitive to these local disturbances. The theory is applicable for the settling of discrete particles of uniform size, shape, density, and specific gravity, which usually is not the case in practice. Also, the theory does not adequately take into account other parameters such as the location of the inlet and outlet, and the depth and shape of the pond.

DESIGN CONSIDERATIONS FOR IMPROVED PERFORMANCE

Actual efficiencies of all ponds with positive efficiencies during the baseline and rainfall event were plotted against their computed detention time (Figure 28) and overflow velocity (Figure 29). The overflow velocity was calculated as the ratio of pond discharge to pond surface area, and the detention time was calculated as the ratio of the total water storage to the discharge from the pond. These two plots indicate that for the ponds sampled under this study, a suspended solids removal efficiency of approximately 90 percent can be obtained if the pond has:

(1) A detention time of at least 10 hours

(2) An overflow velocity of less than about 2×10^{-5} m/sec.

One of the reasons for the good performance of Pond 6 was the accumulation of debris and trees at the inflow to the pond, resulting in a reduction of the inflow velocity and consequent deposition of sediment before it reached the pond

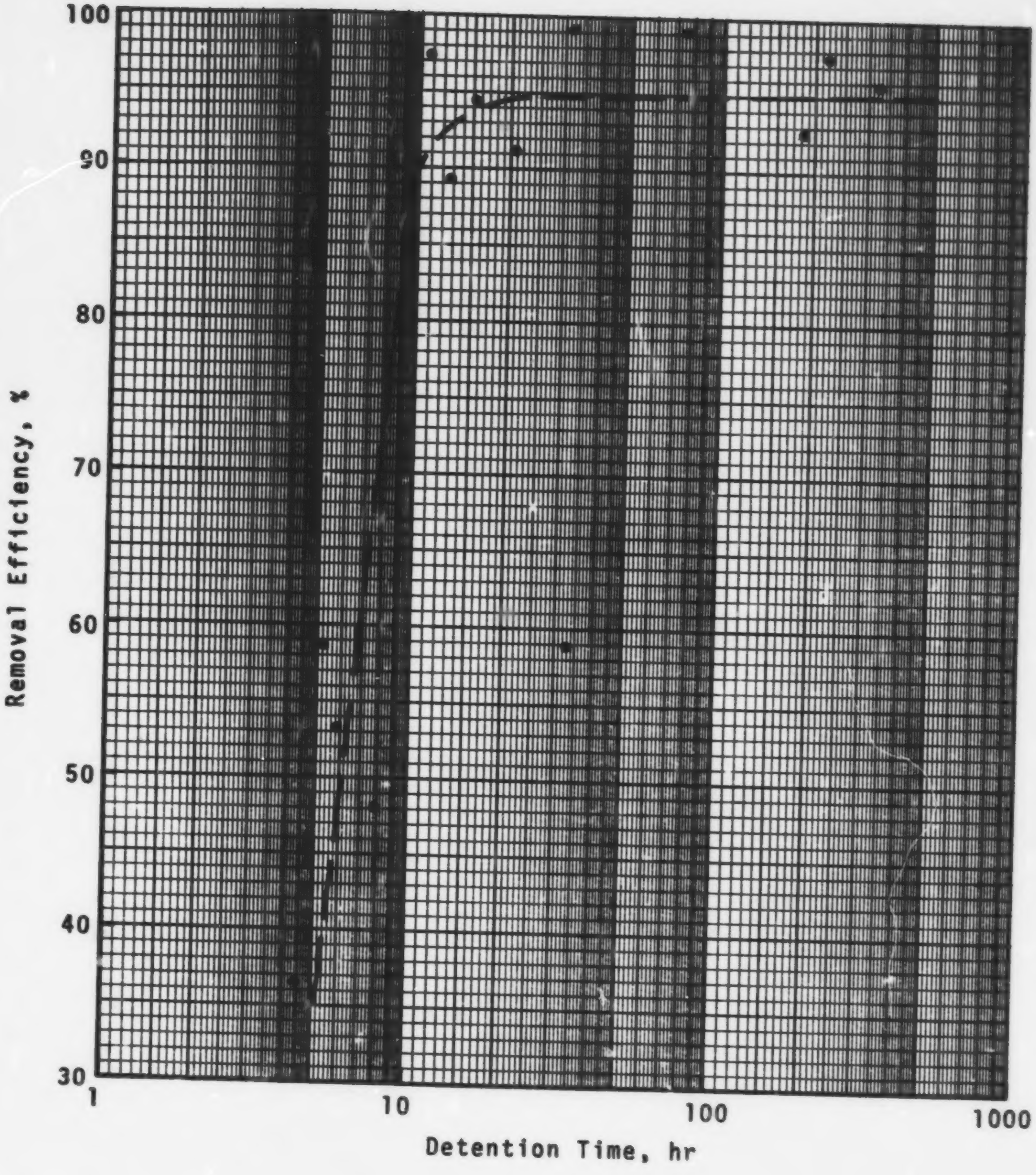

FIGURE 28. Removal Efficiency versus Detention Time.

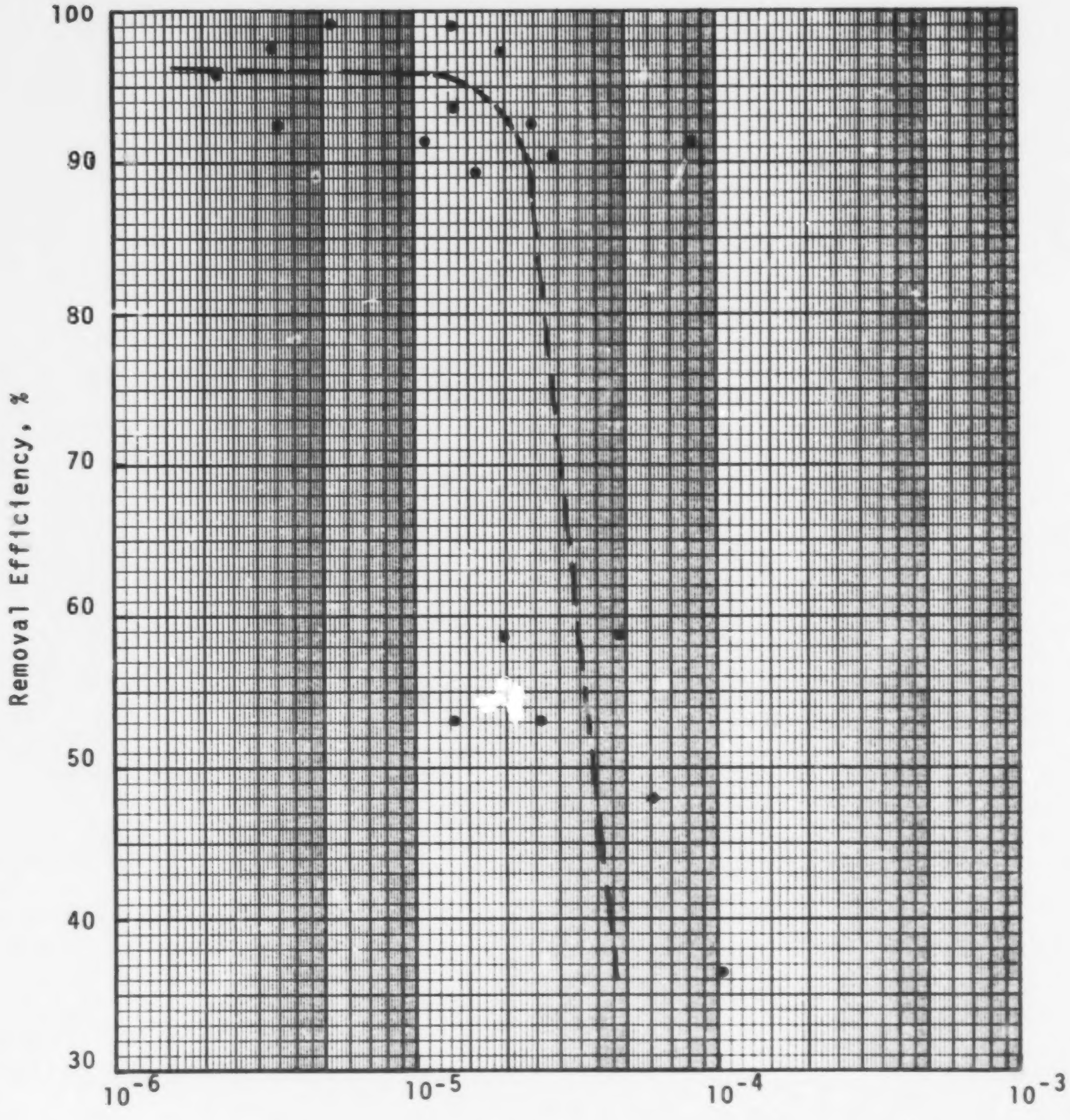

FIGURE 29. Removal Efficiency versus Overflow Velocity

or in the upper reaches of the pond. By using this principal and constructing some type of energy dissipater(s) in the stream just upstream of the pond, the amount of suspended solids removed by the pond can be increased. One such device could be a log structure as shown in Figure 30 .

Sediment basins constructed across the natural stream may solve the sedimentation problem only temporarily. Locating the basin off stream by temporarily diverting the main stream, as shown in Figure 31, will help solve some of the problems inherent in in-stream sediment basins. After the completion of mining, the stream can be rerouted to its original alignment with a minimum disturbance of the environment.

Some of the problems of disposing of accumulated sediment can be solved by building an embankment across the main stream and providing the required storage capacity of the basin by excavating the stream bed, as shown in Figure 32 . The object of this approach is to leave the stream at its original profile after the mining activity has ceased and the embankment has been removed.

Perforations in the outflow riser pipe allow sediment to flow through the openings. The concept of using a perforated riser pipe in a sediment control structure for surface mining is questionable. This type of riser is generally used in sediment ponds in urbanizing areas. The ponds are designed to be dry ponds for safety purposes, i.e., to prevent drownings.

Instead of using a perforated riser pipe, the siphon arrangement as shown in Figure 33 could be tried to achieve twofold benefits:

(1) There are no perforations for sediment to escape through as the pond fills.

(2) The siphon pipe can be located at the approximate elevation of the desired cleanout level of the pond. This would help in implementing cleanout procedures when the required pond storage capacity is used up.

WATER QUALITY CRITERIA

Designing a pond to meet a specific water quality criterion is difficult, because of the many variables which are not normally known but which must be taken into account. The factors which must be known or assumed before an analysis can be made are:

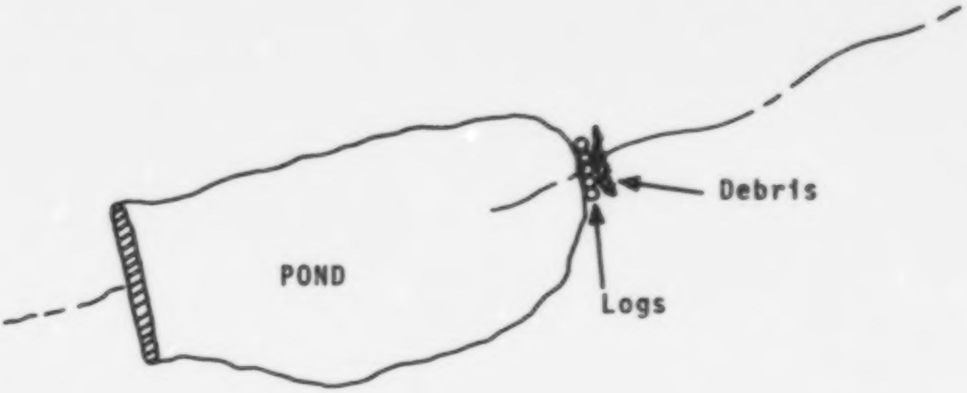
Debris
POND
Logs

FIGURE 30. Plan View of Conceptual Log Structure Upstream of a Sediment Pond, Acting as an Energy Dissipator

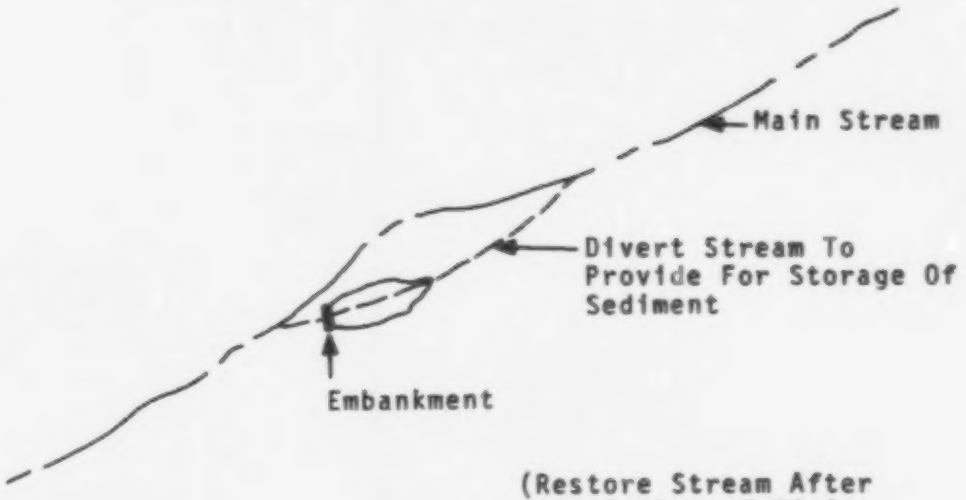
Main Stream
Divert Stream To Provide For Storage Of Sediment
Embankment
(Restore Stream After Completion of Mining Activity)

FIGURE 31. Plan View of Off-Stream Sediment Pond

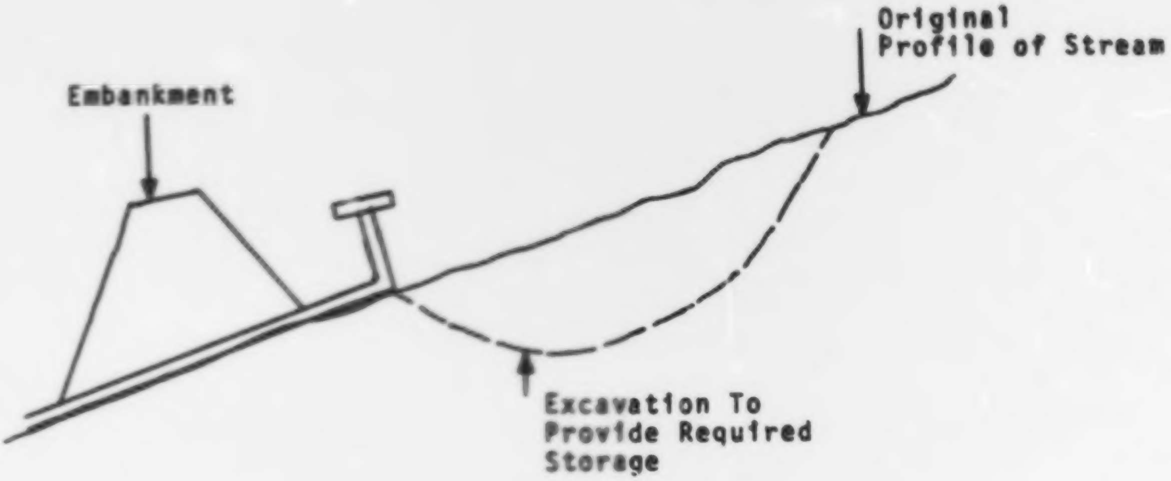
Original
Profile of Stream
Embankment
Excavation To
Provide Required
Storage

FIGURE 32. Profile View of Stream Excavation for Sediment Storage

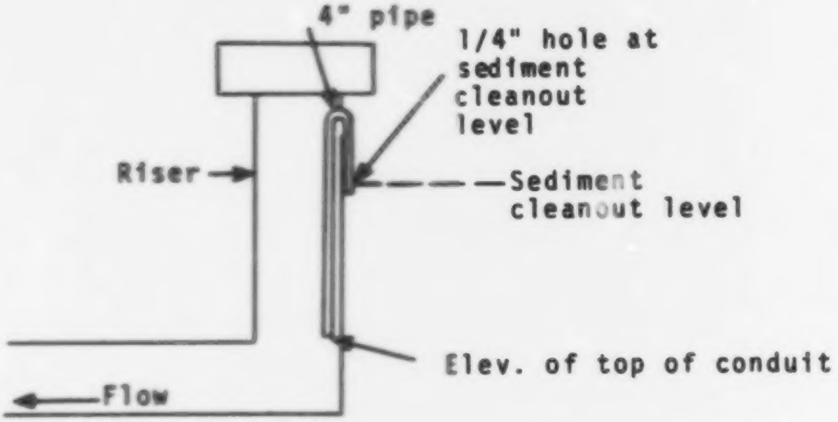
4" pipe
1/4" hole at
sediment
cleanout
level
Riser
Sediment
cleanout level
Elev. of top of conduit
Flow

FIGURE 33. Siphon Arrangement in Riser Pipe.

(1) Design flow rate

(2) Expected grain size distribution of the incoming suspended sediment

(3) Anticipated suspended solids concentration in the inflow

(4) Specific gravity of the incoming solids

(5) Anticipated pond water temperature

Nevertheless, for comparative purposes an analysis was made on one of the measured ponds to determine the pond area requirements for various assumed effluent standards. To illustrate this relationship, the analysis was performed on Pond 3 for the inflow conditions existing during the baseline sampling period. Under these conditions, the pond had a measured outflow water quality of 200 mg/l. The theoretical suspended solids removal efficiency agreed closely with the measured removal efficiency (see Table 3).

Figure 34 shows the computed, required pond areas versus effluent quality. As can be seen from this figure, in this case the area requirements rapidly become very large as the required effluent quality approaches 100 mg/l or less.

This example illustrates the type of analyses which should be performed before any effluent quality criteria are chosen. As illustrated, the pond area required to meet a specific effluent water quality criterion may become quite large if high flow rates, many fine-grained particles, or high suspended solids concentrations are present in the inflow. Pond areas can be reduced, of course, by reducing any of these three variables. For example, the suspended solids concentration and amount of fine-grained particles in the inflow can be reduced by good and timely site erosion control and reclamation practices. Flow rates can be reduced by building off-channel ponds.

STATE REGULATIONS

The design criteria currently used are thorough, especially in Kentucky and West Virginia, for such things as dam construction, etc. However, no State has regulations which provide for maximum suspended solids removal. There are also definite gaps in defining the requirements for the removal and disposal of the accumulated sediments, requiring the maintenance and repair of sedimentation ponds, and providing for the dismantling of the structure after the mining

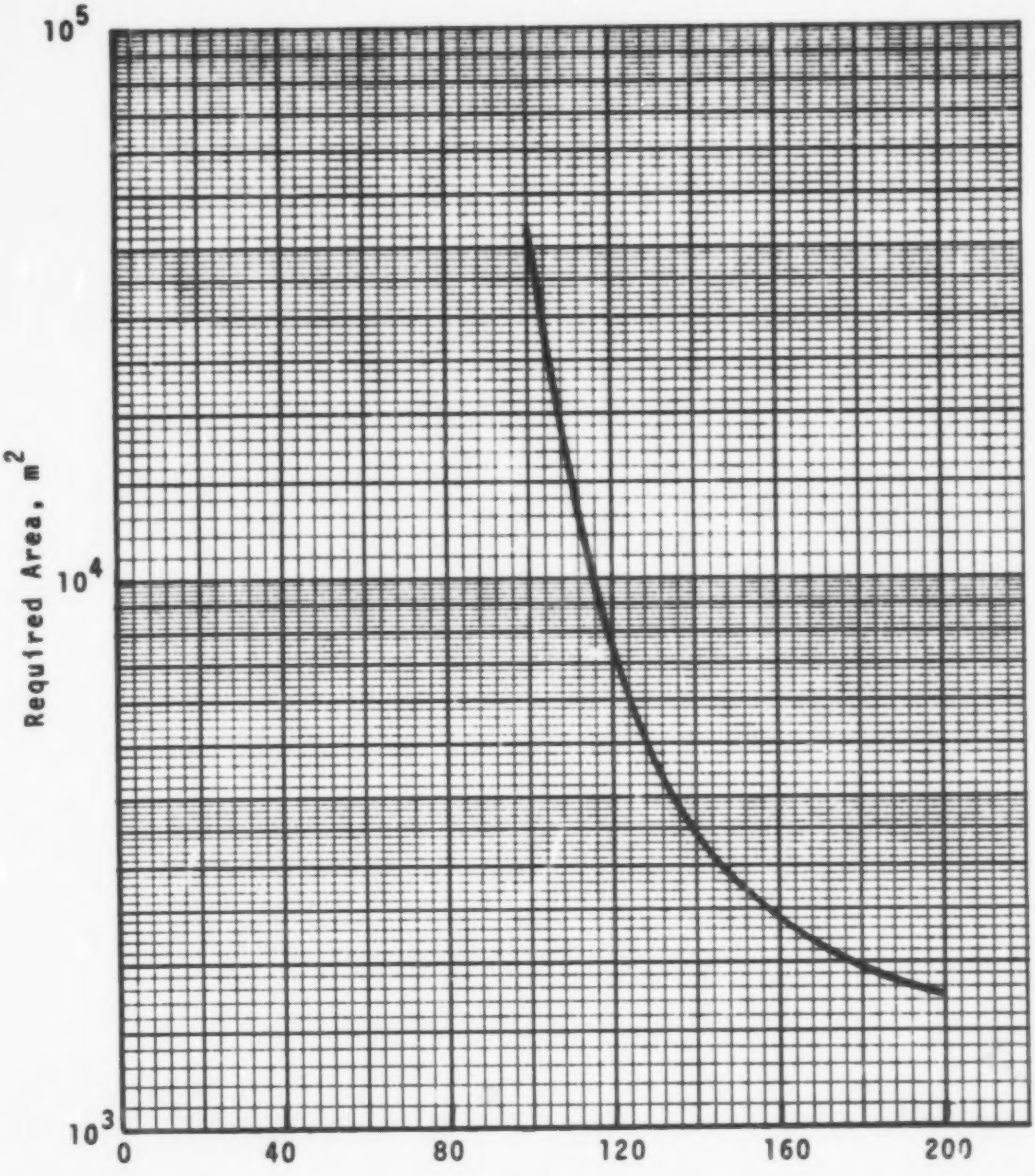

FIGURE 34. Required Pond Area versus Effluent Quality - Pond 3, Baseline Conditions

activity is terminated. The structures which are built across a natural stream may fail during high intensity storms, discharging both the accumulated sediment and the earth embankment itself into the stream. The problem of sediment control from surface mining activity is thus only temporarily solved in such cases since the sediment pollution was only postponed until some time after the mining has ceased. At that time the solution becomes more difficult because the mine operator is not available to rectify the problem.

Ideally, the entire surface mine sediment control scheme should be planned and executed in four phases:

(1) Preparation of adequate designs and drawings

(2) Construction in accordance with approved design and drawings

(3) Maintenance and provisions for mitigation of off-site and downstream damages

(4) Disposal of trapped sediments after completion of mining activity

The first phase is adequately covered in the State of Kentucky and West Virginia regulations, but all the other phases need more consideration. Timely and proper consideration of all of the four phases will yield better results. Construction of a highly effective pond without considering the possible downstream, off-site effects of the pond discharge can often cause more erosion and sedimentation problems than it solves. As can be seen in Pond 8, the pond was well designed and well built, but the discharge from the pond flowed directly across an unimproved dirt road, resulting in erosion of the road and the transport of the eroded sediments into the natural waterway. Also, the efficiency of Pond 6 during both baseline and rainfall event conditions was measured to be over 95 percent, but the overflow from the emergency spillway was causing serious erosion problems to a dirt road downstream.

SECTION IX

REFERENCES

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APPENDIX A

Contained herein are comparative summaries of the various design, construction, and maintenance aspects of the regulations pertaining to surface mine sedimentation ponds in the three States of primary interest, i.e., Kentucky, Pennsylvania, and West Virginia. For the sake of comparison, the SCS standards and specifications for sediment basins adopted by the State of Maryland have been included since the design standards for sediment control structures in the State of Maryland are considered to be among the most advanced in the country.

Also included in Table A-11 are brief summaries of the status of regulations that pertain to the use of sediment ponds in conjunction with surface mining activities in other eastern States and by TVA.

Table A-1. CONSTRAINTS ON SIZE AND TYPE OF BASIN

State	General	Safety	Structure Height	Storage Volume	Contributing Drainage Area
SCS (Maryland)	Specification applies only to sediment basins that are temporary in nature and will be removed upon completion of the development period. The practice applies primarily to areas where land grading operations are planned or underway. It is used as a temporary measure until areas above the installation are permanently protected against erosion by vegetative or mechanical means.	--	Class "X" - 10 feet Class "B" - water surface area at crest elevation of pipe spillway shall not exceed nine (9) feet measured upward from the original stream bed.	Class "X" - less than 1 million gallons storage capacity below the pipe spillway crest	Class "B" - the drainage area shall not exceed one hundred fifty (150) acres.
Kentucky	Standards establish minimum acceptable quality for design and construction of debris basins located in predominately rural or agricultural areas in Eastern Kentucky. The debris basin must conform to all state and local laws and/or regulations pertaining to storage of water.	Failure of the structure would not result in loss of life; in damage to homes, commercial or industrial buildings; main highways, or railroads; in interruption of the use or service of public utilities; or damage existing water impoundments.	The vertical distance between the lowest point along the center line of the dam, excluding the channel section, and the crest of the emergency spillway does not exceed 20 feet.	The product of the storage times the effective height of the dam does not exceed 3000, where the storage is defined as the original volume (acre-feet) in the reservoir at the elevation of the crest of the emergency spillway and the effective height of the dam is defined as the difference in elevation (feet) between the emergency spillway crest and the lowest point in the cross-section taken along the centerline of the dam.	Not to exceed 300 acres
Pennsylvania	--	--	--	--	--
West Virginia	Standard establishes minimum acceptable quality for the design and construction of sediment dams located in predominantly rural or agricultural area in West Virginia.	Same as Kentucky (See above)	The vertical distance between the lowest point along the center line of the dam and the crest of the emergency spillway does not exceed 15 feet.	Not to exceed a surface area at emergency spillway crest greater than 10 acres.	Not to exceed 200 acres.

Table A-2. REQUIRED STORAGE CAPACITY

State	Requirement
SCS (Maryland)	Site should be selected to provide adequate storage for not less than 0.5 in. per acre of drainage area. Volume for trap efficiency calculations shall be the volume below the emergency spillway crest or pipe spillway crest if there is no emergency spillway.
Kentucky	Sediment pool shall have a minimum capacity (from the lowest elevation in the reservoir of the crest of the principal spillway) of 0.2 acre-ft per acre of disturbed area in the watershed. The disturbed area includes all land affected by previous operations that are not presently stabilized and all land that will be affected throughout the life of the structure.
Pennsylvania	$V = (AIC) + (AIC/3)$ V = volume in cu ft A = maximum area draining to the pit in sq ft I = rainfall (in.) per 24 hr detention time (hr) C = constant = % of rainfall not absorbed by soils (runoff)
West Virginia	The sediment pool shall have a minimum capacity (from the lowest elevation in the reservoir to the crest of the principal spillway) to store 0.125 acre-ft per acre of disturbed area in the watershed. The disturbed area includes all land affected by previous operations that is not presently stabilized and all land that will be affected during surface mining and reclamation work.

Table A-3. BASIN CLEAN-OUT

State	Requirement
SCS (Maryland)	Sediment basin shall be cleaned out when the effective storage capacity drops below 0.2 inches per acre of drainage area. The elevation corresponding to this level shall be determined and given in the design data as a distance below the top of the riser.
Kentucky	No provisions
West Virginia	The basin shall be cleaned out when the sediment accumulation approaches 60 percent of the design capacity. The design and construction drawings shall indicate the corresponding elevation.
Pennsylvania	No provisions.

Table A-4. SPILLWAY DESIGN CAPACITY CRITERIA

State	Principal spillway	Emergency spillway	Remarks
SCS (Maryland)	Must be designed to handle not less than 5" runoff from the drainage area for 24 hrs. (i.e., 5" runoff or 0.21 cfs per acre of drainage area)	Minimum capacity will be that required to pass the peak flow from design storm (10 yr. frequency) less any reduction creditable to the pipe spillway.	Combined capacity of pipe emergency spillway will, where applicable, be designed to handle a ten year frequency storm.
Kentucky	Minimum spillway size is based on total drainage area above the structure and can be obtained from prepared tables.	Designed to safely carry the expected peak rate of discharge from a 10-year frequency storm. The 10-year frequency peak discharge can be obtained from charts prepared for that purpose.	Must have one foot freeboard between the maximum design flow elevation.
Pennsylvania	Based on 4" rainfall over a 24 hr. period times (x) the detention time in days or parts of a day (6 hr. minimum detention time)	---	---
West Virginia	Minimum size is based on total drainage area above structure and can be obtained from prepared tables.	Designed to safely carry the expected peak rate of discharge from a 10-year frequency storm. The 10-year frequency peak discharge can be obtained from prepared figures. Emergency Spillway may be waived when the height of the embankment is less than 5 feet and when the drainage area is 20 acres or less.	Must have one foot of freeboard between max. design, flow elevation in emergency spillway and the top of the dam.

Table A-5. INLET STRUCTURE DESIGN CRITERIA

State	Criteria
	A. Crest Elevation
SCS (Maryland)	When used in conjunction with emergency spillways, the crest elevation of the riser shall be at least 1 ft. below the elevation of the control section of the emergency spillway. If no emergency spillway is provided, the crest elevation of the riser shall be at least 3 ft. below the crest elevation of the embankment.
Kentucky	The minimum difference in elevation between the crest of the principal spillway and the emergency spillway on any structure shall be 1.5 feet.
Pennsylvania	No provision.
West Virginia	The crest of the principal spillway shall be located at the maximum elevation of the sediment pond. When the emergency spillway is not required, the crest elevation of the riser shall be at least 2 ft below the crest elevation of the embankment.
	B. Riser Perforations
SCS (Maryland)	The upper portion of the riser shall be perforated with 1-1/2 in. diameter holes spaced 9 in. vertically and 10-12 in. horizontally all around. The perforated portion shall be the top 1/2 to 2/3 of the riser.
Kentucky	Slots located in a horizontal plan in the top one-half (1/2) of the riser shall be made as shown in Exhibit F of Kentucky Standards. In areas where water treatment may be required, a deviation from this requirement will be considered.
Pennsylvania	No provisions.
West Virginia	Metal drop inlets when perforated shall be done so throughout the top 2/3 of their length with 3/4 in. diameter holes spaced 8 in. vertically and 12 in. horizontally center to center. Non-metal drop inlets shall be ported to permit draining the pond in approximately 5 days. (Such ports shall be similar to those described for the metal drop inlets).

Table A-5. INLET STRUCTURE DESIGN CRITERIA(cont.)

State	Criteria
	C. Anti-Vortex Device
SCS (Maryland)	An anti-vortex device shall be used on the top of the riser if the discharge values in the appendexed charts are used. If no anti-vortex device is used, discharge values given in the charts must be reduced by 50 %. An approved anti-vortex device is a thin, vertical plate normal to the centerline of the dam and firmly attached to the top of the riser. The plate dimensions are: length = diameter of the riser plus 12 in.; height = diameter of the horizontal pipe.
Kentucky	An approved anti-vortex device is required on the principal spillway inlet. (See Kentucky Standards Exhibit F.)
Pennsylvania	No provision.
West Virginia	An anti-vortex device shall be installed on the principal inlet. 1. It shall consist of a thin, vertical plate normal to the centerline of the dam and firmly attached to the top of the riser. The plate dimensions shall be: length = diameter of the riser plus 12 in.; height = diameter of the horizonal conduit; or 2. It shall consist of a horizontal circular plate having a diameter 2 ft greater than the drop inlet and firmly mounted 1.5 ft above the crest of the inlet.
	D. Trash Rack
SCS (Maryland)	An approved trash rack shall be securely attached to the top of the riser.
Kentucky	A suitable trash rack will be provided where the drainage area will contribute trash to the reservoir area.
Pennsylvania	No provision.
West Virginia	A suitable trash rack will be provided where the drainage area will contribute trash to the reservoir area.

Table A-5. INLET STRUCTURE DESIGN CRITERIA(cont.)

State	Criteria
	E. Base
SCS (Maryland)	The riser shall have a base attached with a watertight connection and shall have sufficient weight to prevent floatation of the riser. Two approved bases are: (1) A concrete base 18 in. thick with the riser imbedded 6 in. in the base. The base should be square with each dimension 1 ft greater than the riser diameter. (2) A 1/4 in. minimum thickness steel plate welded all around the base of the riser to form a watertight connection. The plate shall be square with each side equal to 2 times the riser diameter. The plate shall have two ft of stone gravel or tamped earth placed on it to prevent floatations.
Kentucky	The inlet shall have a base, usually concrete, attached with a watertight connection.
Pennsylvania	No provision.
West Virginia	Same as SCS (Maryland) criteria.

Table A-6. ANTI-SEEP COLLAR CRITERIA

State	Criteria
SCS (Maryland)	Conduits through embankments consisting of materials with low silt-clay fractions shall be provided with anti-seep collars where the pipe diameter is 10 in. or greater. Seep length should be increased approximately 10%. All Class "B" basins shall have a minimum of one anti-seep collar.
Kentucky	All conduits through the embankments are to be provided with anti-seep collars. They shall be placed along the conduit within the saturated zone of the embankment at distances of not more than 25 ft. Collars shall be of the number and size required to increase the seepage path along the conduit, a distance equal to 15% of the length of the conduit within the embankment. The anti-seep collars shall extend a minimum of 2.0 ft from the conduit in all directions.
Pennsylvania	No provision.
West Virginia	All conuits through the embankment are to be provided with a minimum of three anti-seep collars, except when the embankment is 5 ft or less. When the embankment is 5 ft or less, 2 collars will be required. The collars will be at 15 ft intervals with the middle collar at the centerline of the dam. The anti-seep collars shall extend a mimimum of 2 ft from the conduit in all directions. The collars and their connections to the pipe shall be water-tight.

Table A-7. EMERGENCY SPILLWAY CONTROL STRUCTURE CRITERIA

Parameter	SCS (Maryland)	Kentucky	Pennsylvania	West Virginia
1. INLET CHANNEL				
a. Length of level Section	10 ft	Minimum of 30 ft	No provision	Minimum distance of 20 ft if $Hp \leq 2.5$ ft, 30 ft if $Hp > 2.5$ ft
b. Side slopes	Not steeper than 2:1	2:1	2:1	2:1
c. Bottom width	Same as control section	Minimum of 10 ft	-	Same as exit channel
2. CONTROL SECTION				
a. Minimum bottom Width	8 ft	10 ft	-	10 ft
3. EXIT CHANNEL				
a. Bottom width	-	Minimum of 8 ft	No provision	Minimum 10 ft
b. Side slopes	Not steeper than 2:1	Rock 1/4:1 Earth 2:1	No provision	Rock 1/4:1 Earth 2:1
c. Configuration	-	Trapezoidal	No provision	Trapezoidal
d. Bottom slope	-	Determined from Chart #5 Kentucky Standards	No provision	Determined from chart #1, WV Standards

HP = Height of pool above emergency spillway control section.

Table A-8. EMERGENCY SPILLWAY MAXIMUM PERMISSIBLE VELOCITY

		Type of spillway	
State		Earth	Rock*
SCS (Maryland)		6 ft/sec	-
Kentucky	1. 2.	5 ft/sec 12 ft/sec if adequate protection provided+	14 ft/sec
Pennsylvania		No provision	-
West Virginia	1. 2.	5 ft/sec up to 12 ft/sec if adequate protection is provided++	14 ft/sec

* A spillway is classed as a rock emergency spillway when durable bedrock occurs throughout the level section and in the exit channel to a point opposite the downstream toe of the dam. Durable bedrock is defined as a layer of continuous bedrock equal or greater in thickness than the depth of flow through the spillway at the control section.

+ Spillways excavated in earth shall be protected through the level section when the exit channel velocity exceeds 5 feet per second. A maximum velocity of 12 ft per second will be allowed where adequate protection is provided. The exit channel shall be protected by using well graded riprap having a maximum size of 18 in. and an average size of from 9-12 in. This riprap shall be placed at a minimum thickness of 1.5 ft through the bottom and sides of the control section and exit channel to a point beyond the toe of the embankment.

When the exit channel velocity is from 10.0 to 12.0 ft per second, the riprap shall be placed at a minimum thickness of 2.0 ft and have a maximum size of 25 in. and average size of 15-18 in.

++ Spillways excavated in earth shall be protected throughout the level section and the exit channel with durable rock riprap when the exit channel velocity falls between 5 ft per second and 12 ft per second. The rock riprap will be placed in a 1.5 ft thick blanket through the bottom and sides of the level section and exit channel. Twenty-five percent of the rock will be 18 in. or slightly larger. The remaining 75% shall be well graded material consisting of sufficient rock small enough to fill the voids between the larger rocks. Shale shall not be used for riprap.

Table A-9. FREEBOARD REQUIREMENTS

State	Freeboard requirement
SCS (Maryland)	Minimum freeboard shall be 1.0 ft for sediment basins with emergency spillways, and 2.0 ft for those with no emergency spillway.
Kentucky	The settled elevation of the structure shall be less than 2 ft above the emergency spillway.
Pennsylvania	No provision.
West Virginia	There shall be one ft of freeboard between the maximum design flow elevation in the emergency spillway and the top of the dam. When the emergency spillway is not required, the crest elevation of the riser shall be at least 2 ft below the crest elevation of the embankment.

Table A-10. EMBANKMENT CRITERIA

Design parameter	SCS (Maryland)	Kentucky	Pennsylvania	West Virginia
Height	10 ft for Class "X" basin 15 ft for Class "B" basin	Must be high enough to prevent overtopping while storing the required sediment and floodwater volumes and passing the peak discharge from an unrouted 10-yr frequency storm through the emergency spillway plus 1 (one) foot freeboard and meet the requirements of paragraph A.3-4[*]	No provision	Must be high enough to have one foot of freeboard between the maximum design flow elevation in the emergency spillway and the top of the dam.
Top width	8 ft minimum	Top width is function of structure height.[+]	No provision	14 foot minimum
Side slopes	Maximum of 2:1 for Class "X" maximum of 2-1/2:1 for Class "B"	Maximum of 2-1/2:1	No provision	Maximum of 3:1 on upstream side and 2:1 on downstream side
Cutoff trench	No provision	See[++]	No provision	**
Settlement Allowance	10% settlement allowance	5%	No provision	5%
Utilities under embankment	No provision	Must be relocated, reconstructed or modified to provide durability, strength and flexibility equal in all respects to principal spillway	No provision	Must be relocated
Safety	No provision	Fencing required[#]	No provision	Fencing required

Notes to Table A-10

* Paragraph A.3-4

The vertical distance between the lowest point along the center line of the structure, including the channel section, and the crest of the emergency spillway does not exceed 20 feet.

+ The minimum top width of the structure shall be as follows:

Maximum Structure height-feet	Minimum top width-feet
15 or less	10
15-25	12
25-40	14

++ A cutoff to relatively impervious material shall be provided under the structure along the center line and up the abutment to the elevation of the crest of the principal spillway. The cutoff trench should have a bottom width adequate to accommodate the construction equipment but shall not be less than 8 feet. The trench shall have minimum side sloped of 1:1.

** The elevation of the top of a compacted cutoff will not be lower than the crest of the principal spillway. The cutoff trench should have a bottom width adequate to accommodate the construction equipment but shall not be less than 8 feet. The trench shall have a minimum side slope of 1:1. The cutoff trench shall be located on the embankment center line and be of sufficient depth to extend into a relatively impervious layer of soil or to bedrock.

The embankment, pool area and vegetated spillway shall be fenced as needed to exclude livestock.

Table A-11. SEDIMENT BASIN REGULATIONS OF OTHER STATES INVESTIGATED

State	Regulation
Illinois	While the amended 1971 Surface-Mined Land Conservation and Reclamation Act does not specifically address sediment pond use and design criteria, they do recognize that sediment ponds are sometimes needed as an erosion control measure and are built according to defined engineering standards.
Indiana	Legislation governing the reclamation of surface mined lands does not include criteria for the design of sedimentation ponds. Where there is a requirement for a sediment pond then Soil Conservation Service Criteria is utilized .
Virginia	The Commonwealth of Virginia's coal surface mining law does not prescribe precise design criteria and specifications for sediment pond construction. The law, however, does specify that a plan for drainage control be attached to the operations plan which shall provide for the proposed scheme of drainage control.
Tennessee	Since the State of Tennessee is a relatively small producer of coal it lacks the personnel and research facilities necessary for establishing sediment basin design criteria. When sediment ponds and control structures are required, operators and engineers utilize the State of West Virginia's "Drainage Handbook" which has proven effective in Tennessee operations.
TVA	The Tennessee Valley Authority has no specific guidelines for sediment pond design. Depending on where TVA purchases coal, individual states specifications are followed in sediment pond design criteria. In states where standards don't exist TVA encourages the operator to construct numerous small log or rock dams in drainage areas below the operation. Guidelines for the use and design of silt traps are adapted from a detailed erosion control manual prepared in the late 1930's by TVA engineers.

APPENDIX B

BACKGROUND INFORMATION ON SEDIMENT PONDS

THEORY OF SETTLING

Sedimentation is the separation of suspended particles that are heavier than water from water by gravitational settling. On the basis of the concentration and the tendency of the particles to interact, four general classifications of the manner in which particles settle can be made.[5] It is not only common to have more than one type of settling taking place at a given time during a sedimentation operation, but it is possible as well to have all four occurring simultaneously. The four classifications as described by Clark and Ungersma are:[5]

(1) Type-1 settling refers to the sedimentation of discrete particles in a suspension of low solids concentration. Particles settle as individual entities, and there is no significant interaction with neighboring particles. This type of settling is called free or ideal settling.

(2) Type-2 settling is the process whereby a rather dilute suspension of particles coalesce, or flocculate, during the sedimentation operation. By coalescing, the particles increase in mass and settle at a faster rate.

(3) Type-3 settling occurs in suspensions of intermediate concentrations, in which interparticle forces are sufficient to hinder the settling of neighboring particles. The particles tend to remain in fixed positions with respect to each other and the mass of particles settles as a unit. This type of settling is generally called zone settling.

(4) Type-4 settling or compression settling develops when the particles are of such concentration that a structure is formed. Further settling can only take place by compressing the structure. This

type of settling generally takes place in the lower layers of a thick mixture. Compression is due to the weight of particles which are constantly added to the structure by sedimentation from the upper layers.

Ideal Settling

Current practice in the design of sedimentation basins for sediment control assumes the conditions of ideal settling. Performance and design curves for the case of ideal settling are illustrated in Figure B-1. As indicated in Figure B-1, the settling velocity for a spherical particle of a given size and specific gravity is governed by one of three flow regimes: Stokes' Law, Newton's Law, and the Transitional Region. The governing equation for the settling velocity within each flow regime is:[6]

(a) Stokes' Law:

$$V_s = \frac{g}{18\nu}(S_s - 1)D^2 \qquad Re<1$$

(b) Transitional Region:

$$V_s = \left[2.32(S_s - 1)D^{1.6}\nu^{-0.6}\right]^{0.714} \qquad 1<Re<1000$$

(c) Newton's Law:

$$V_s = 1.82\left[g(S_s - 1)D\right]^{0.5} \qquad 1000<Re<25000$$

where:
V_s = critical settling velocity, cm/sec
g = acceleration due to gravity = 981 cm/sec^2
D = diameter of a spherical particle, cm
S_s = specific gravity of the particle
ν - kinematic viscosity of water, cm^2/sec
Re = Reynolds number = $V_s D/\nu$

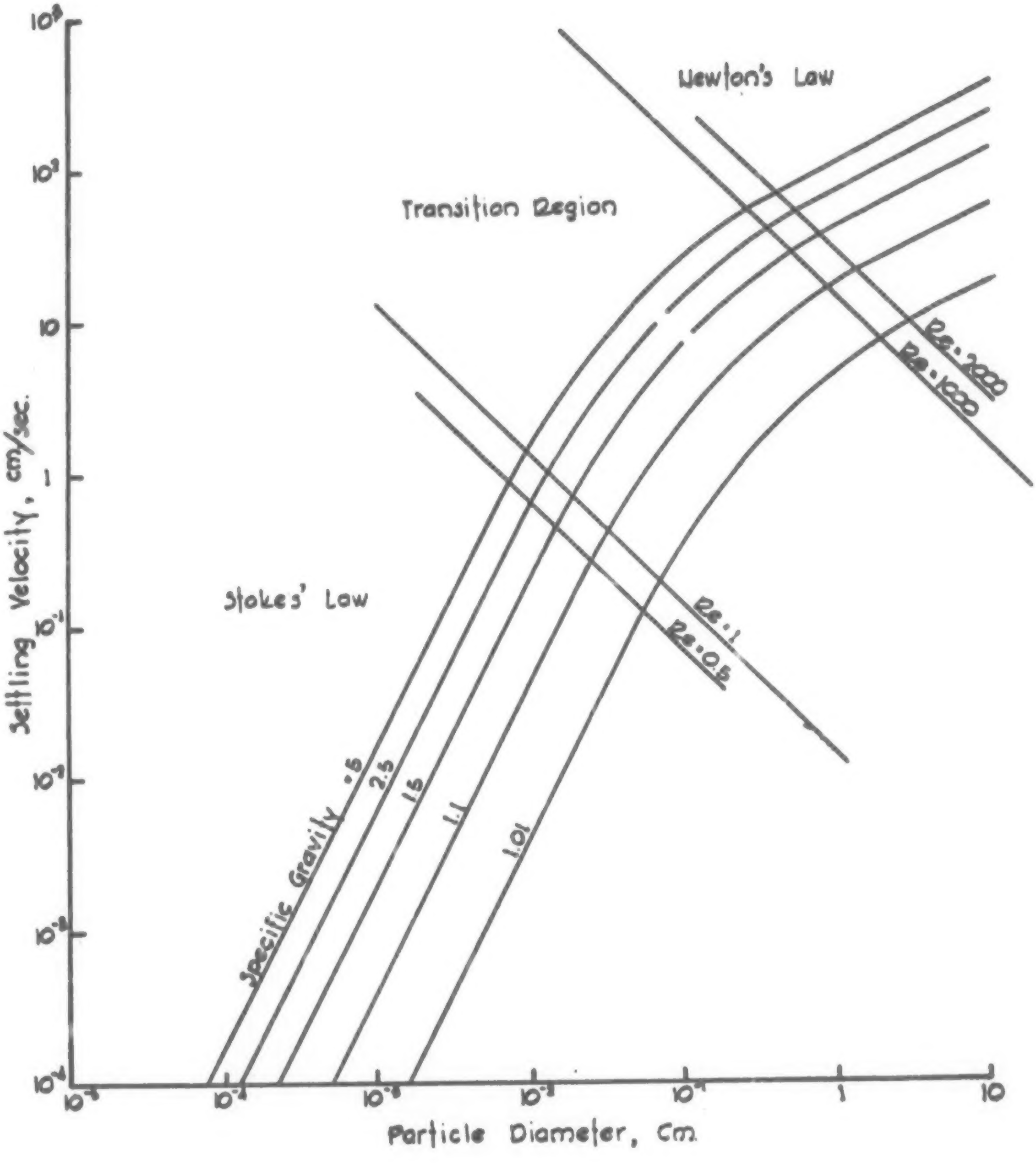

FIGURE B-1. Ideal Settling Velocity for a Sphere (10°C Water)

These equations for V_s are implicit functions of the drag coefficient for spheres. For each flow regime, the drag coefficient for a sphere becomes an approximate unique function of the Reynolds number.

However, suspended particles in water and wastewater are hardly ever spherical. Drag coefficients for spheres, cylinders, and disks differ significantly at high Reynolds numbers (>1000). At low Reynolds Numbers (≤ 10), the setteling velocities of rod-like and disk-like particles are, respectively, 78 and 73 percent of the velocity of an equal-volume spherical particle.[6]

Factors Affecting Ideal Settling

In the design of sedimentation basins under the assumptions of ideal settling conditions, certain allowances must be made for certain factors which affect ideal settling. These factors include scour velocity, turbulence, and short circuiting effects.

Scour Velocity -

The actual dimensions of a clarifier tank or settling basin of any given area are governed by the constraints imposed by the scour velocity present. Scour velocity is defined as the horizontal channel velocity required to start in motion particles of size D, and is given by the equation:[7]

$$v_c = \sqrt{\frac{8B}{F} g\ (S_s - 1)D}$$

where: v_c = scour velocity, cm/sec

B = .04 for unigranular sand

$\geq$ .06 for sticky, interlocking material

F = .02 to .03, friction factor

In settling tanks, the horizontal velocity through the tank should be kept less than v_c so that settled small particles are not scoured from the bottom of the tank. The scour velocity is seen to be independent of the dimensions of the tank.

Turbulence -

The net result of turbulent diffusion is to decrease the removal by settling of some desired particle sizes. Instead of settling, the particles are carried out through the overflow. Camp[7] developed an expression whereby the removal ratio is the fraction of particles of the given size that would be settled with turbulence present in the clarifier. Thus, a removal ratio of 1.0 would mean that all particles of that size or larger would be settled even with turbulence present. This removal ratio is a function of the velocity per unit of surface area of the settling zone. It should be calculated for each settling tank configuration in order to determine if turbulence effects are significant.

Short Circuiting -

The short circuiting phenomenon is defined as the condition which occurs when some of the fluid travels through the settling zone of a tank in less than the detention period.[7] It is emphasized by mixing the tank contents, high inlet velocities, and density currents. A density current is defined as the flow of one fluid into another relatively quiet fluid whose density is different. Density differences between the fluids may be due to differences in temperature, salt content, or suspended solids content. If the detention tank velocity is large enough, density currents will mix in the tank with negligible effects on the overall flow pattern. Such a tank is said to have a stable flow pattern. If density currents remain intact through a tank, then the flow pattern is unstable.

The shape of the concentration dispersion curve versus time is a measure of the flow pattern through a tank. When these curves are plotted in dimensionless terms, they can be used to compare the hydraulic characteristics of different shapes of detention tanks. Table B-1 shows several types of tanks and their measured relative times to the center of area of the corresponding dispersion curve, ta/T, where ta is the "probable flowing through time" of the fluid and T is the detention time. The parameter ta/T is usually less than unity. Smaller values for ta/T yield correspondingly greater short circuiting problems.

As one proceeds down Table B-1, short circuiting is progressively less of a problem. The surface area required by a given type of clarifier can be increased to approximately account for short circuiting as follows:

$$A = F_{sc} \times \frac{Q}{V_s}$$

The short circuiting factor, F_{sc}, in Table B-1 is the reciprocal of ta/T and can be determined separately for each type of detention tank or basin.

Table B-1. SHORT CIRCUITING FOR SETTLING TANKS

Type of Tank	ta/T	Short Circuiting Factor (F_{sc})
Ideal dispersion tank	0.693	
Radial flow circular	0.831	1.2
Wide rectangular (length = 2.4xwidth)	0.925	1.08
Narrow rectangular (length = 17xwidth)	0.903	1.11
Baffled mixing chamber (length = 528xwidth)	0.988	1.01
Ideal basin	1.0	1.0

DESIGN BASIS

Design Parameters

In general, conventional sedimentation basins can be designed to meet one or both of the following criteria:

(a) Retain a percentage of the total suspended solids.

(b) Removal of solids to meet a discharge water quality selected for the receiving body of water.

In ideal settling (discrete particles of uniform size, uniform density, reasonably uniform specific gravity, and fairly uniform shape), the removal efficiency of the suspended solids will be dependent on the surface area of the basin and detention time; the depth of the basin will have little influence, providing horizontal velocities are maintained below the scouring velocity.[5]

Solids Removal -

The ability of the basin to retain the suspended sediment is the primary consideration. The percentage of solids to be removed will be set by one of the two criteria listed above.

If the return water quality is the criteria, the percentage of solids to be removed can be determined by the formula:

$$R(\%\ \text{solids removed}) = \left[1 - \frac{\frac{10^6}{C_1} - 1}{\frac{10^6}{C_2} - 1}\right]100$$

where C_1 = solids concentration of influent, mg/l

C_2 = solids concentration of effluent, mg/l

Design Particle Size -

The particle size to be removed is a function of the percentage of solids to be removed. The particle size in question is obtained by constructing a grain size distribution curve of representative samples of incoming sediment.

Critical Settling Velocity -

The general procedure for sizing a sedimentation basin is to select a critical settling velocity, V_s, corresponding to the minimum particle size to be removed and its specific gravity.[5] The basin is then designed so that all particles that have a terminal velocity equal to or greater than V_s will be removed. The rate at which clarified water is produced is then:

$$Q = AV_s$$

where A is the surface area of the sedimentation basin. The equation can be rearranged to yield:

$$V_s = Q/A = \text{overflow rate}$$

This relationship shows that the overflow rate or surface loading rate, a common basis of design, is equivalent to the settling velocity and that for ideal settling the flow capacity is independent of the depth.

For continuous flow sedimentation, the length of the basin and the time a unit volume of water is in the basin (detention time) should be such that all particles with the design velocity V_s will settle to the bottom of the basin. The design velocity, detention time, and basin depth are related as follows:

V_s = depth/detention time

In actual practice, design factors have to be included to allow for the effects of inlet and outlet turbulence, short circuiting, etc., as previously discussed.

Overflow Rate -

The overflow or surface loading rate used for design purposes should correspond to the peak discharge of the design storm. The return frequency of the design storm is selected to equate the cost of a given design to the probable protection and service it will afford. Return intervals of two to ten years are currently being used.[1]

Storage Considerations -

In the design of conventional sedimentation basins, the quantity of material to be stored is equally as important as the ability of the basin to retain solids. The quantity of material to be stored is estimated by approximate methods such as the Universal Soil Loss Equation[8] or the Musgrave approximation.[9] Rules of thumb are also available. For example, the SCS suggests that the site should be selected to provide adequate storage for not less than 3.14 cm/ha (0.5 inch per acre) of drainage area.[1] The storage requirements and the solids retention capabilities of the sediment basin will be interrelated to the following extent:

(1) The storage volume of the sediment basin will be the product of the surface area of the basin times the total depth minus any freeboard required to prevent bottom scour.

(2) The surface area must be adequate to provide both the required storage capacity and the solids removal capability required to meet return water quality goals.

(3) Nonuniform deposition of materials will reduce the solids retention capability of the containment basin.

APPENDIX C

Contained herein are the measured grain size distributions of the suspended sediment in the inflow to the sampled ponds.

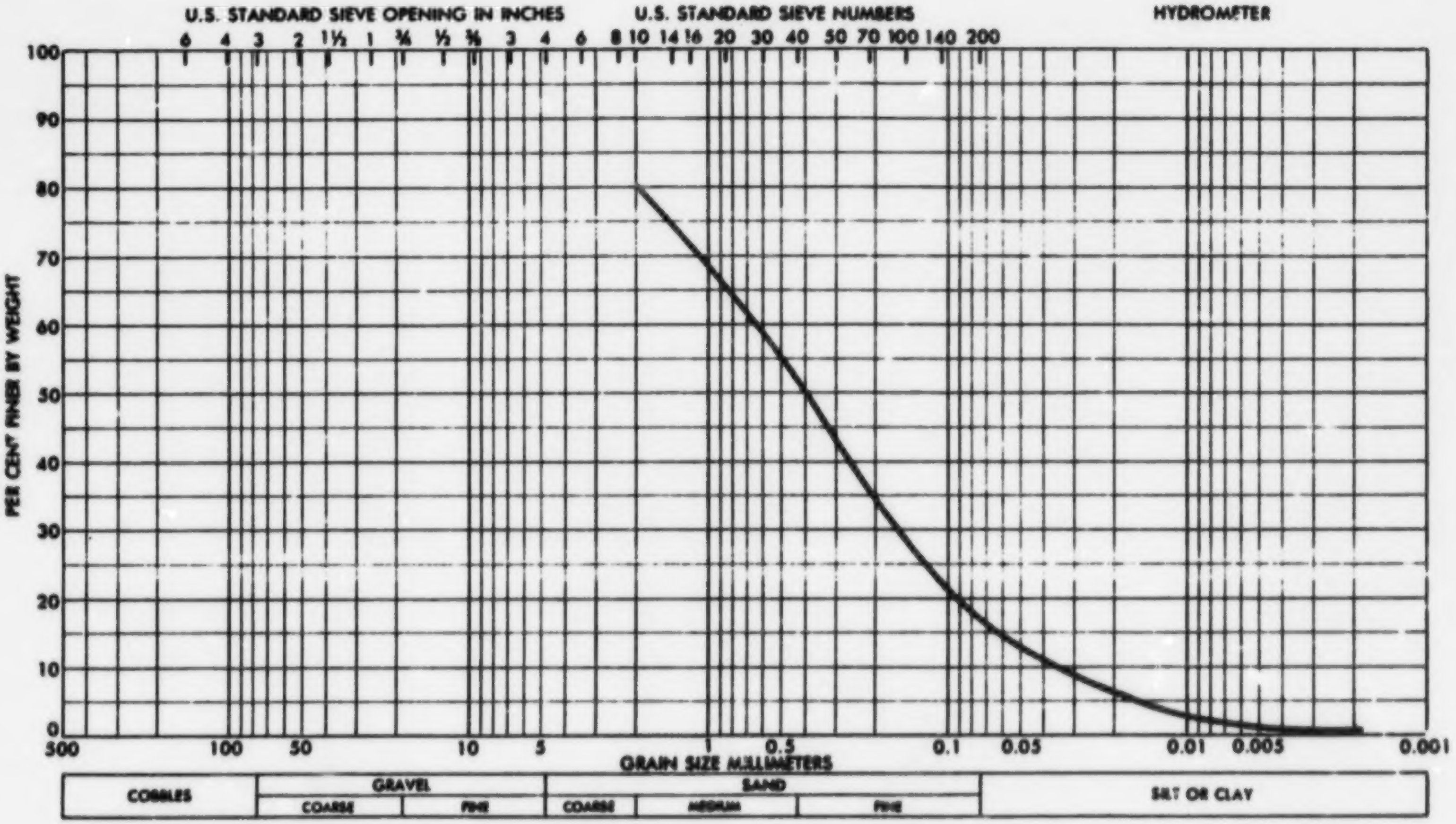

FIGURE C-1. Grain Size Distribution of Incoming Suspended Solids to Primary Pond (Baseline, Pond No. 1)

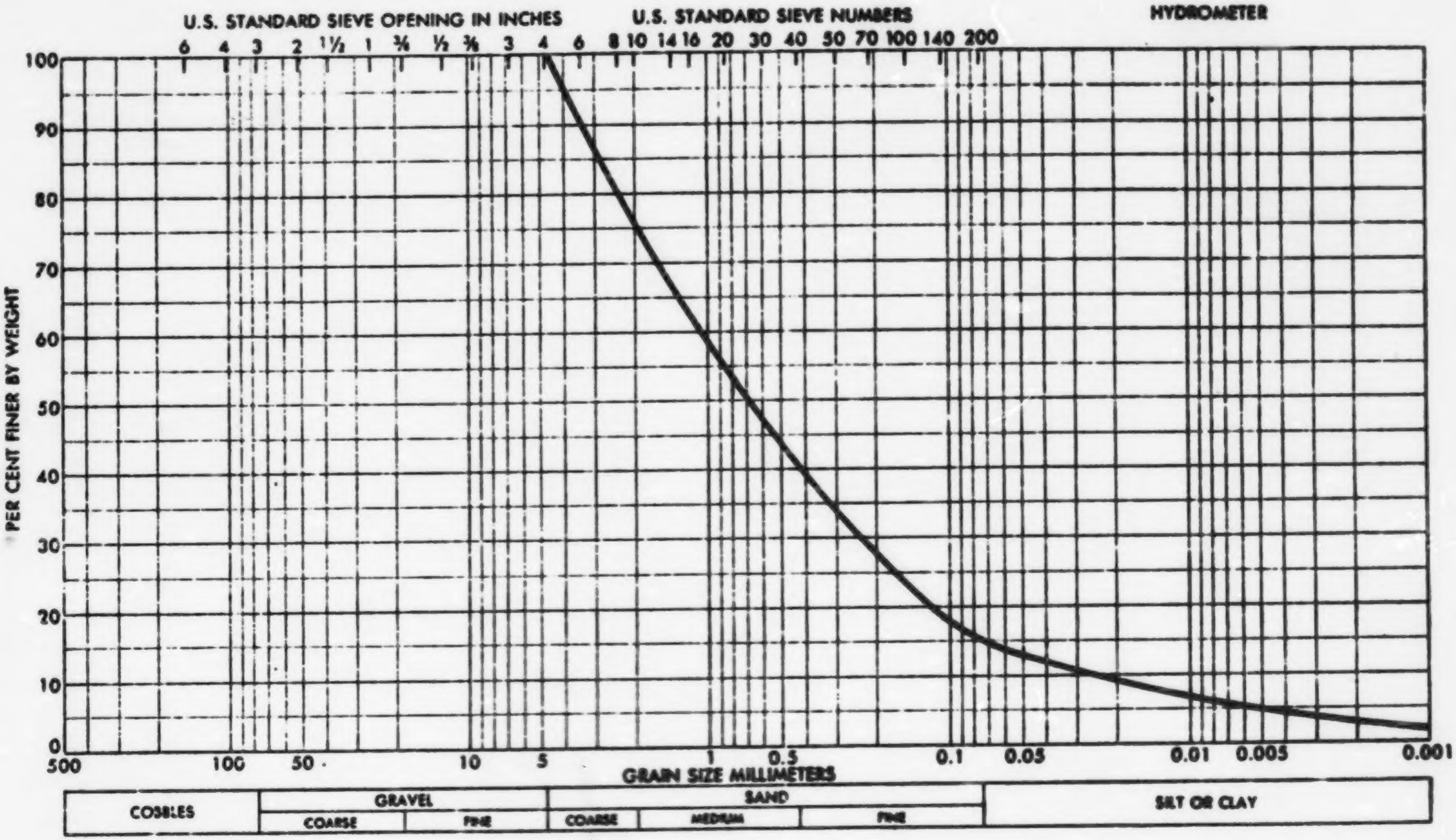

FIGURE C-2. Grain Size Distribution of Incoming Suspended Solids to Primary Pond (Rainfall Event. Pond No. 1)

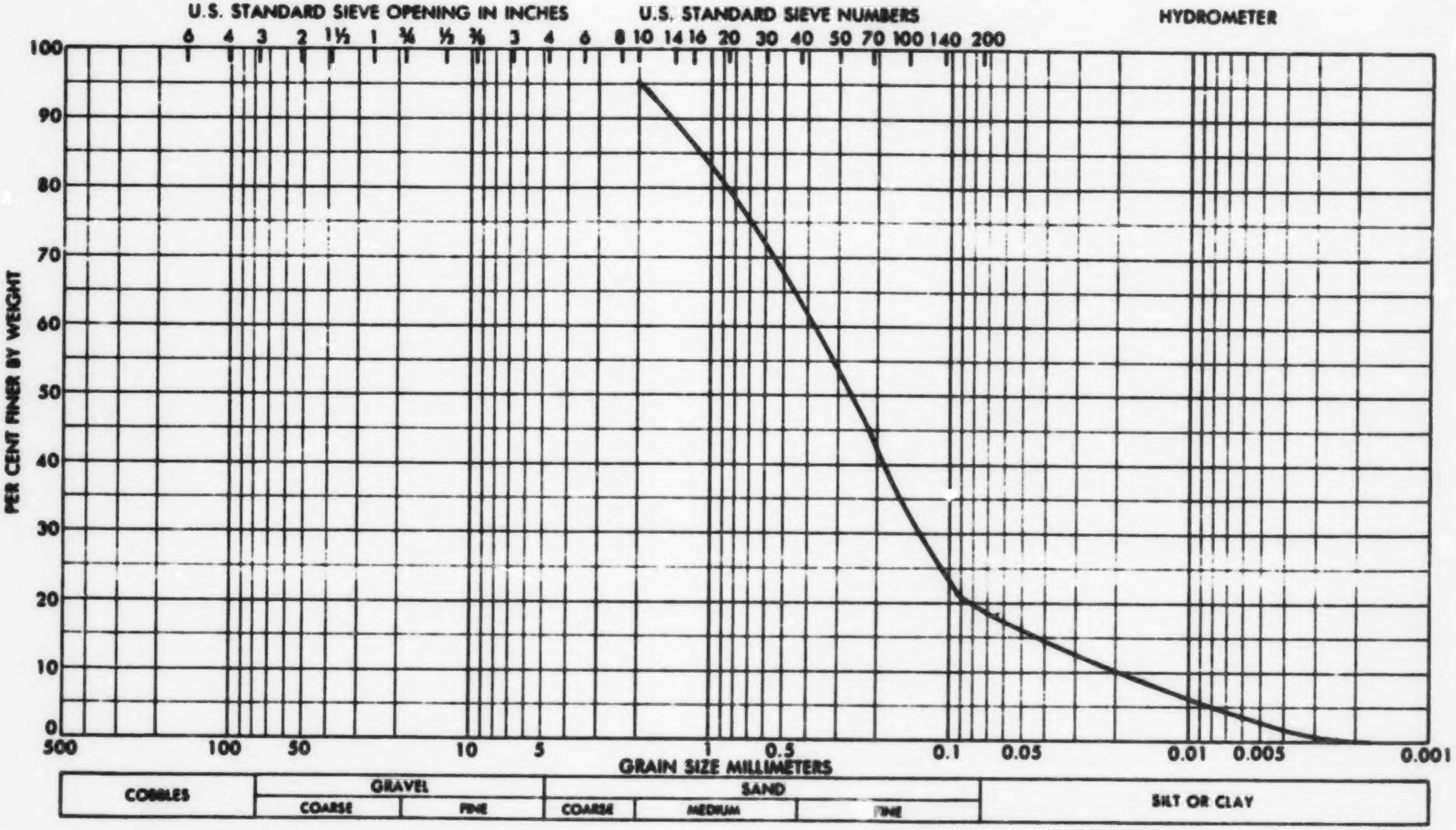

FIGURE C-3. Measured Grain Size Distribution of Inflow Solids, Pond No. 2, Baseline

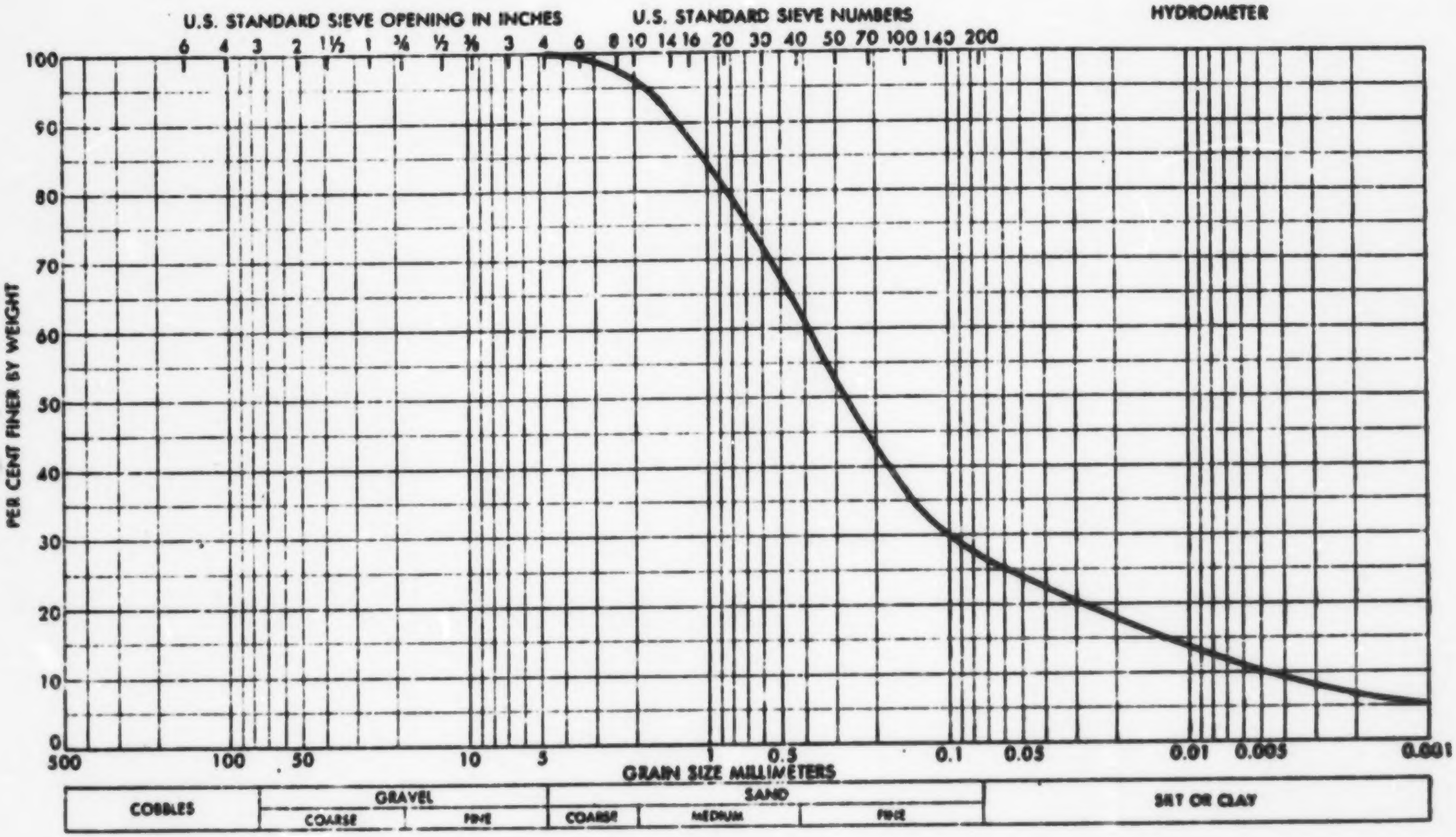

FIGURE C-4. Grain Size Distribution Of Incoming Suspended Solids To Primary Pond. Pond No. 2, Storm Event

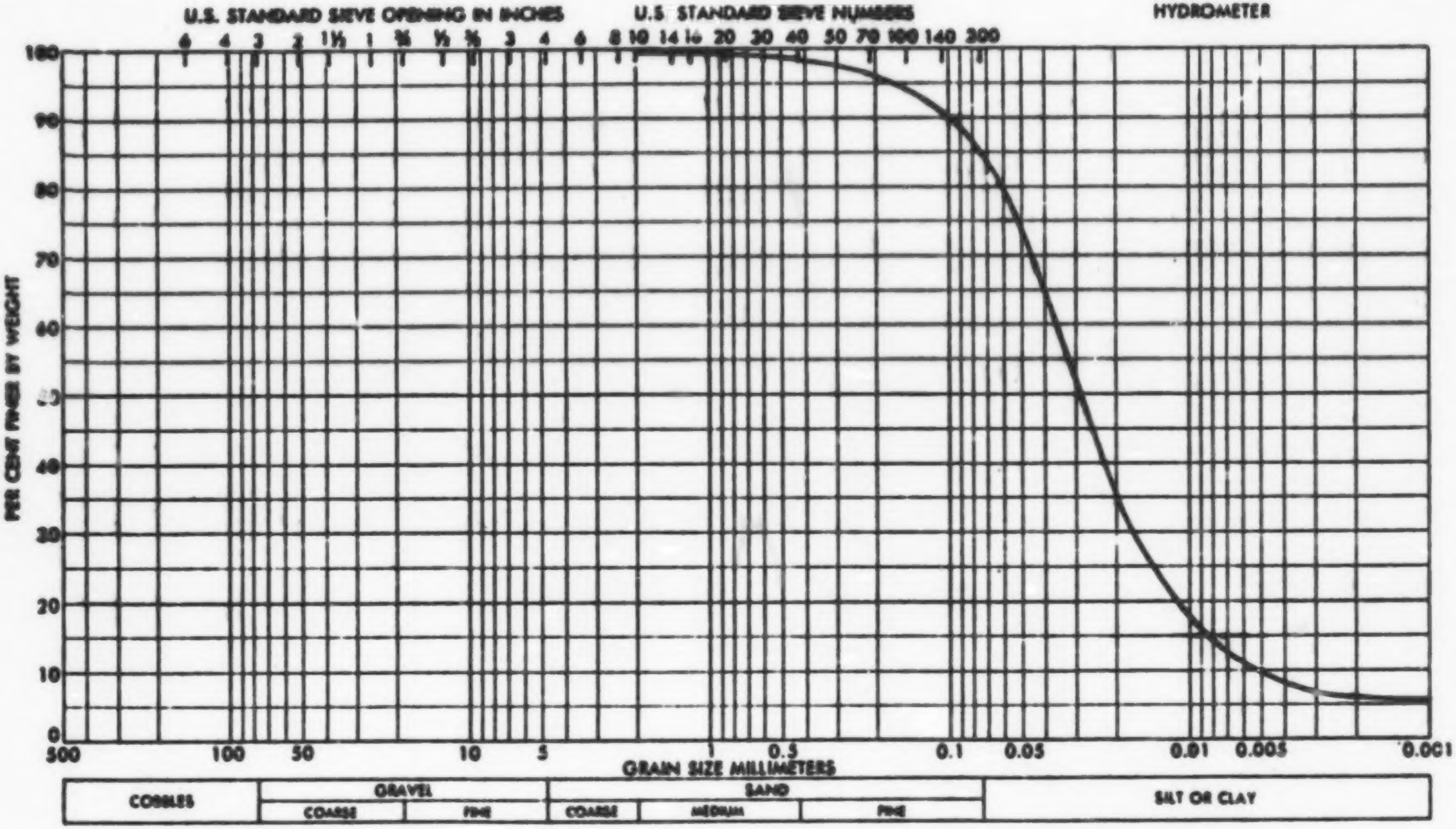

Figure C-5. Grain Size Distribution of Incoming Suspended Solids to the Sediment Basin, Pond No. 3, Baseline and Storm Events

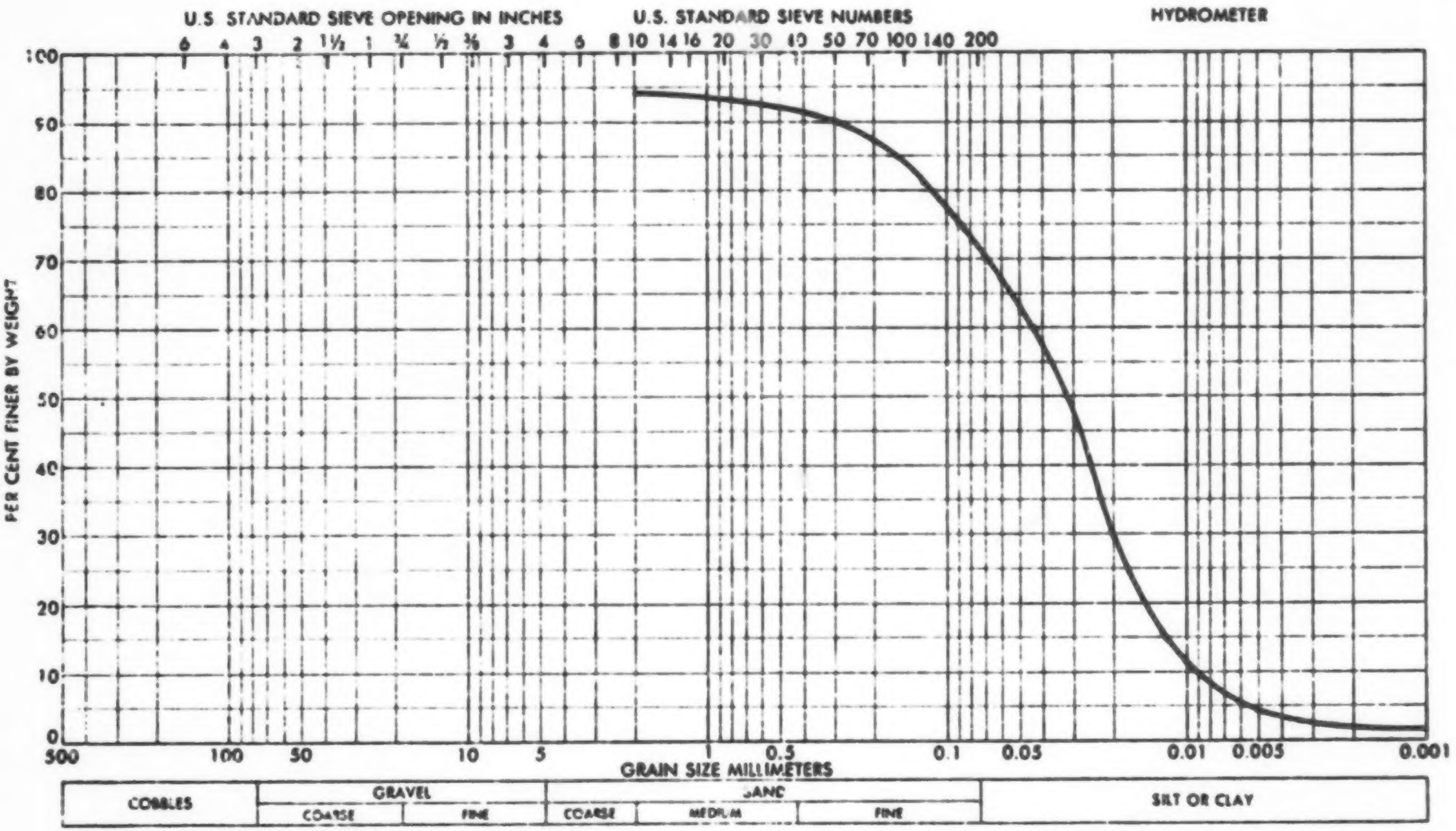

FIGURE C-6. Grain Size Distribution of Incoming Suspended Solids to the Sediment Basin, Pond No. 4, Baseline and Storm Events

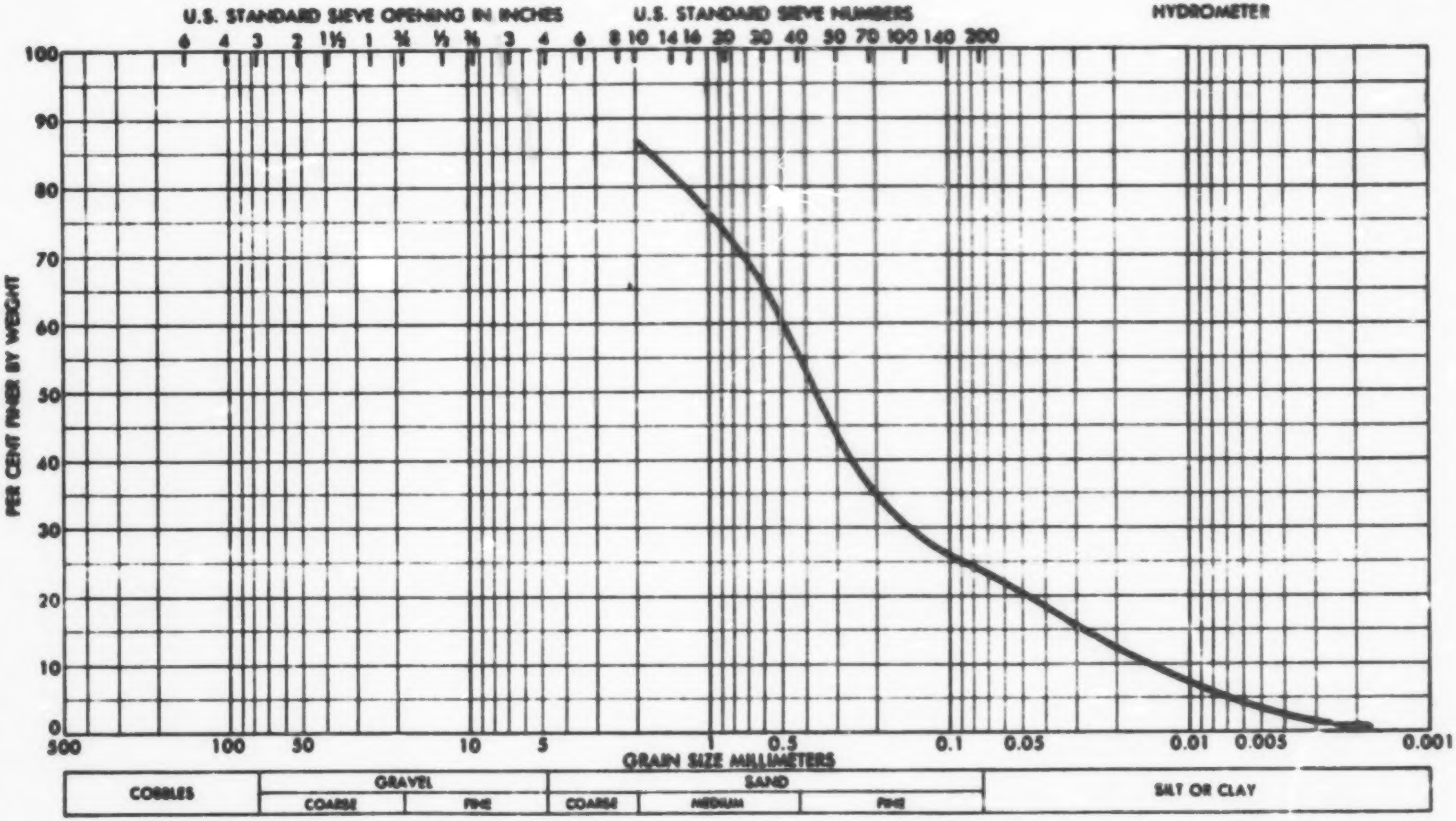

FIGURE C-7. Grain Size Distribution of Incoming Suspended Solids to the Sediment Basin, Pond No. 4, Baseline and Storm Events

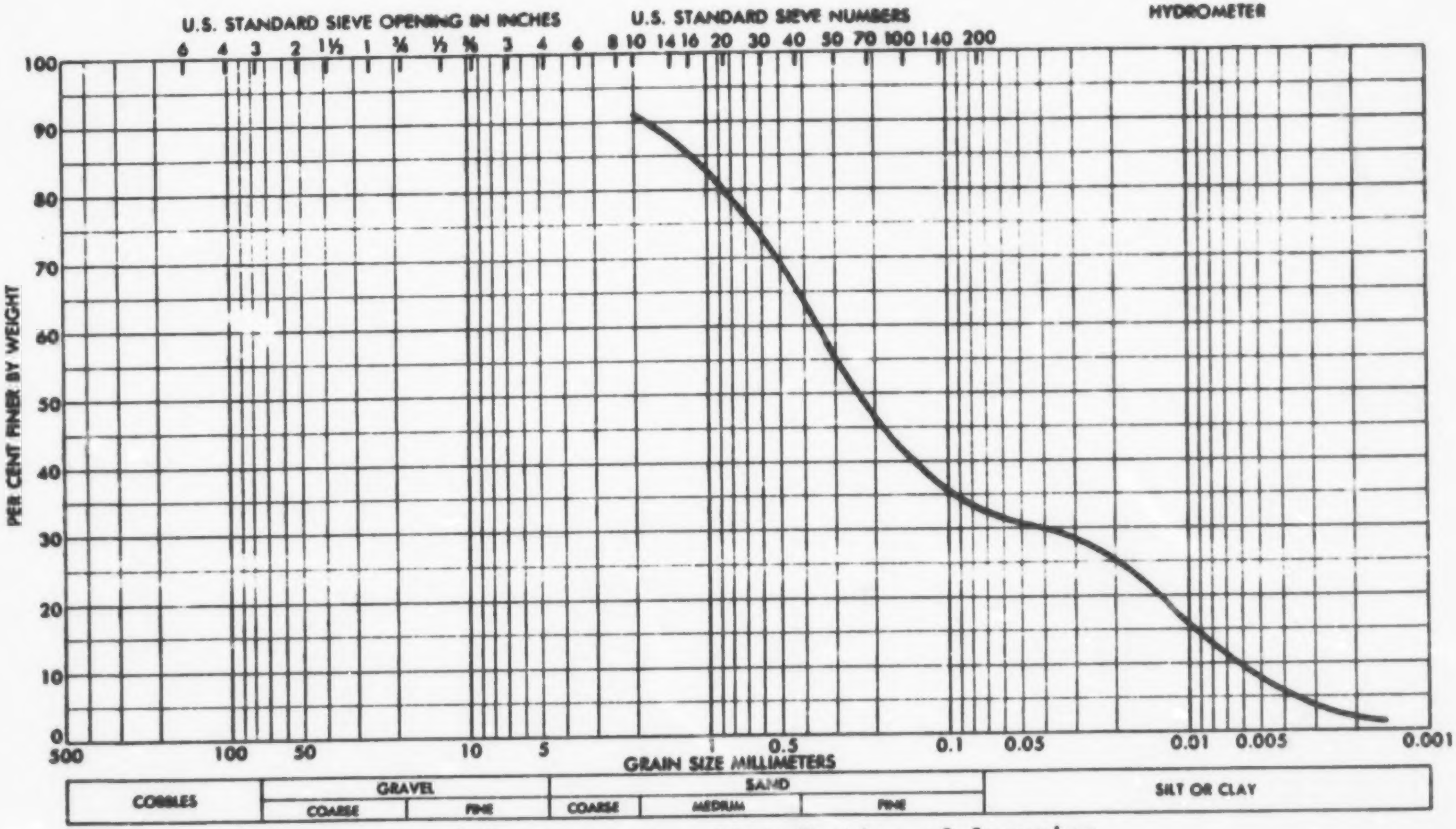

FIGURE C-8. Grain Size Distribution of Incoming Suspended Solids to the Sediment Basin, Pond No. 6, Baseline and Storm Events

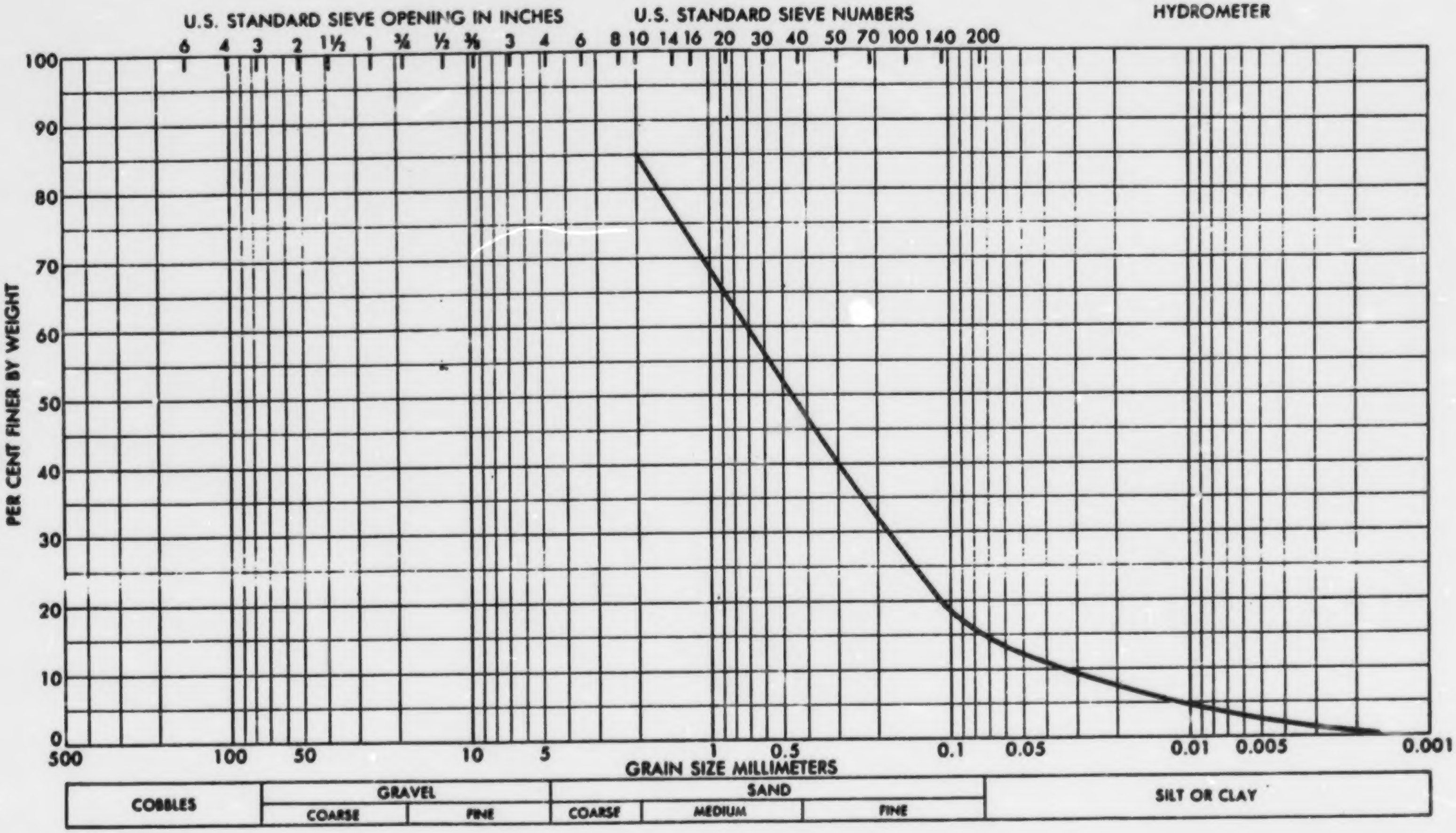

FIGURE C-9. Grain Size Distribution of Incoming Suspended Solids During Baseline Conditions, Pond No. 7

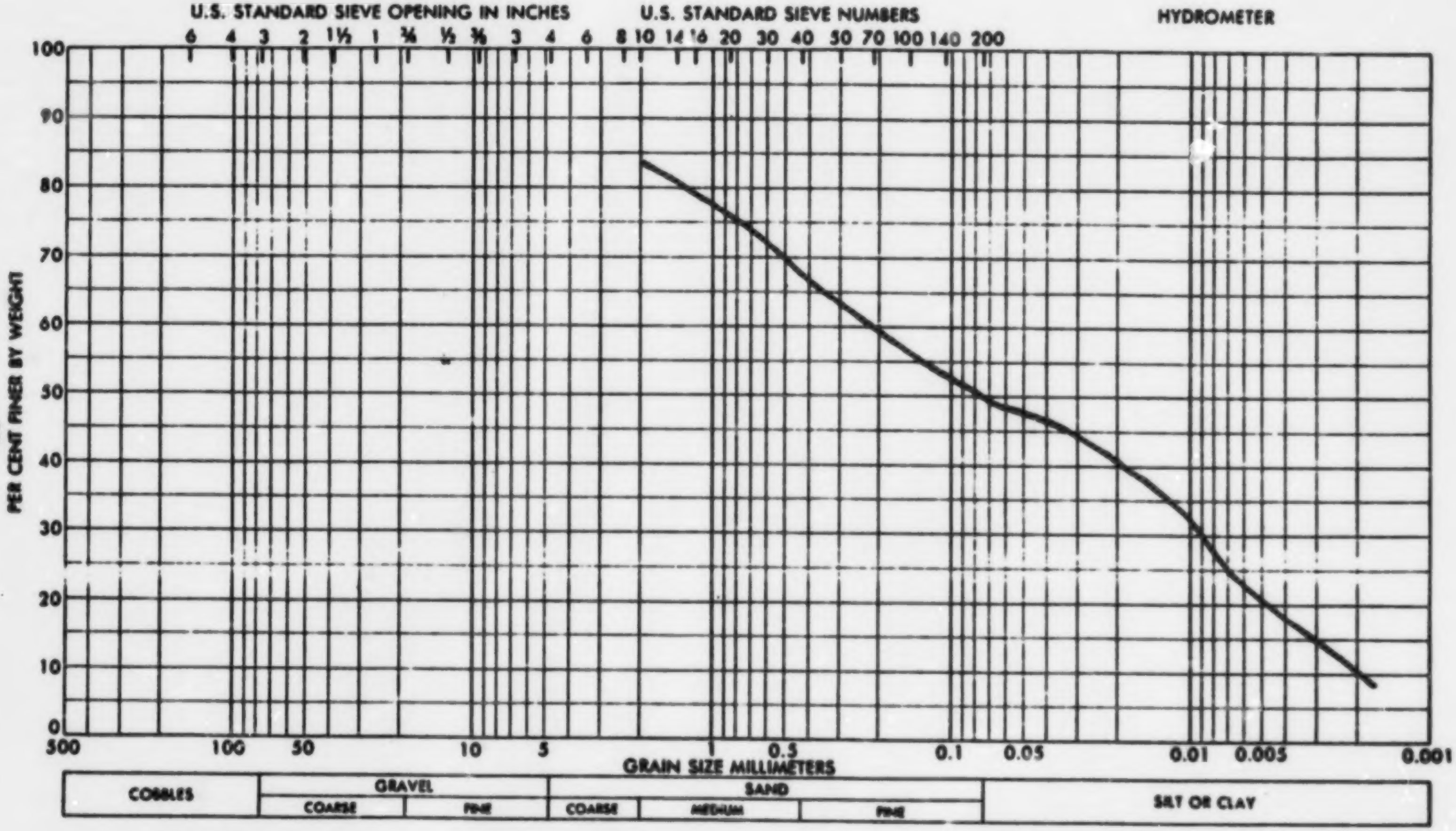

FIGURE C-10. Grain Size Distribution of Incoming Suspended Solids During the Measured Storm Event, Pond No. 7

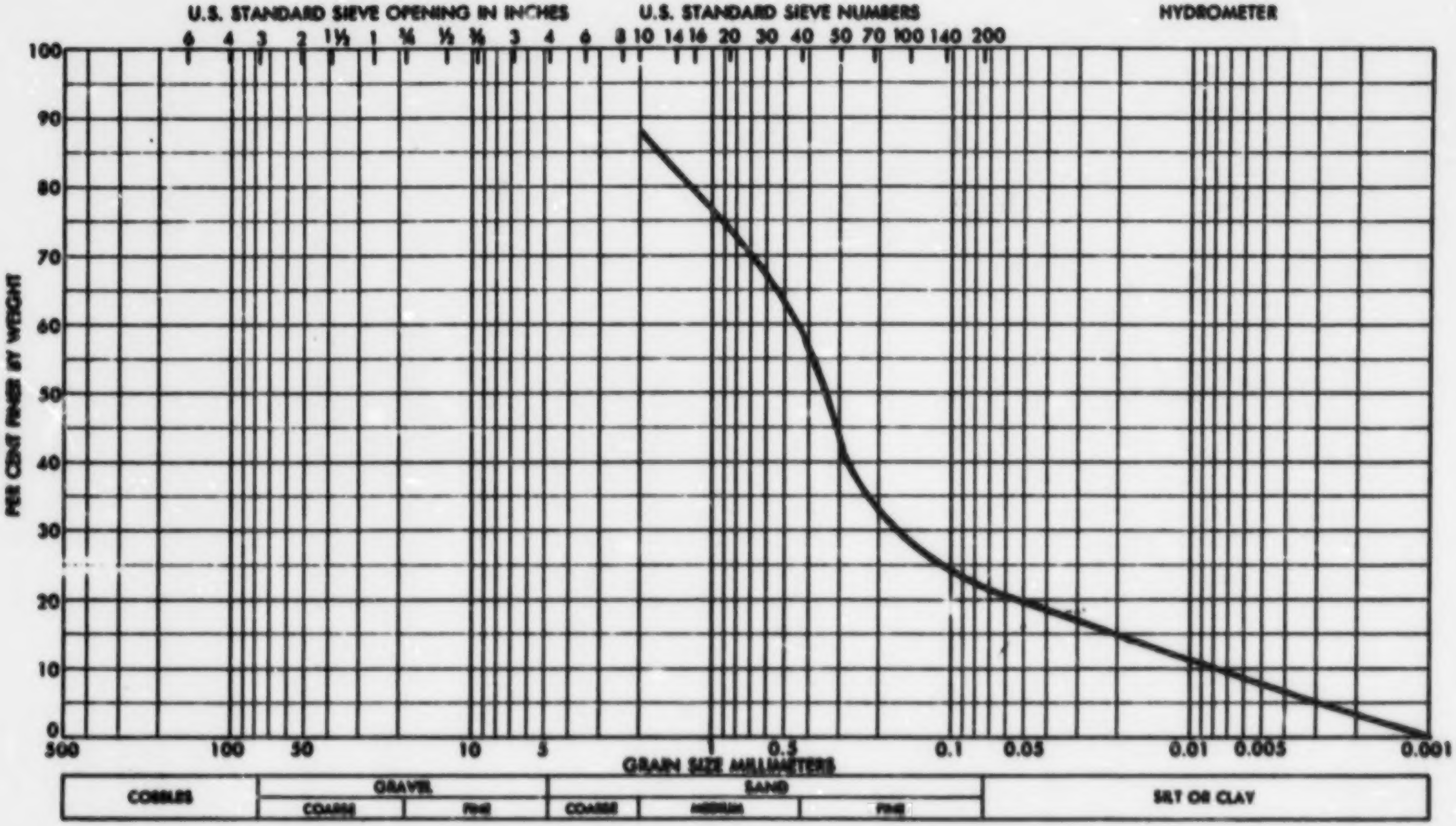

FIGURE C-11.Grain Size Distribution of Incoming Suspended Solids to the Sediment Basin, Pond No. 8, Baseline and Storm Events

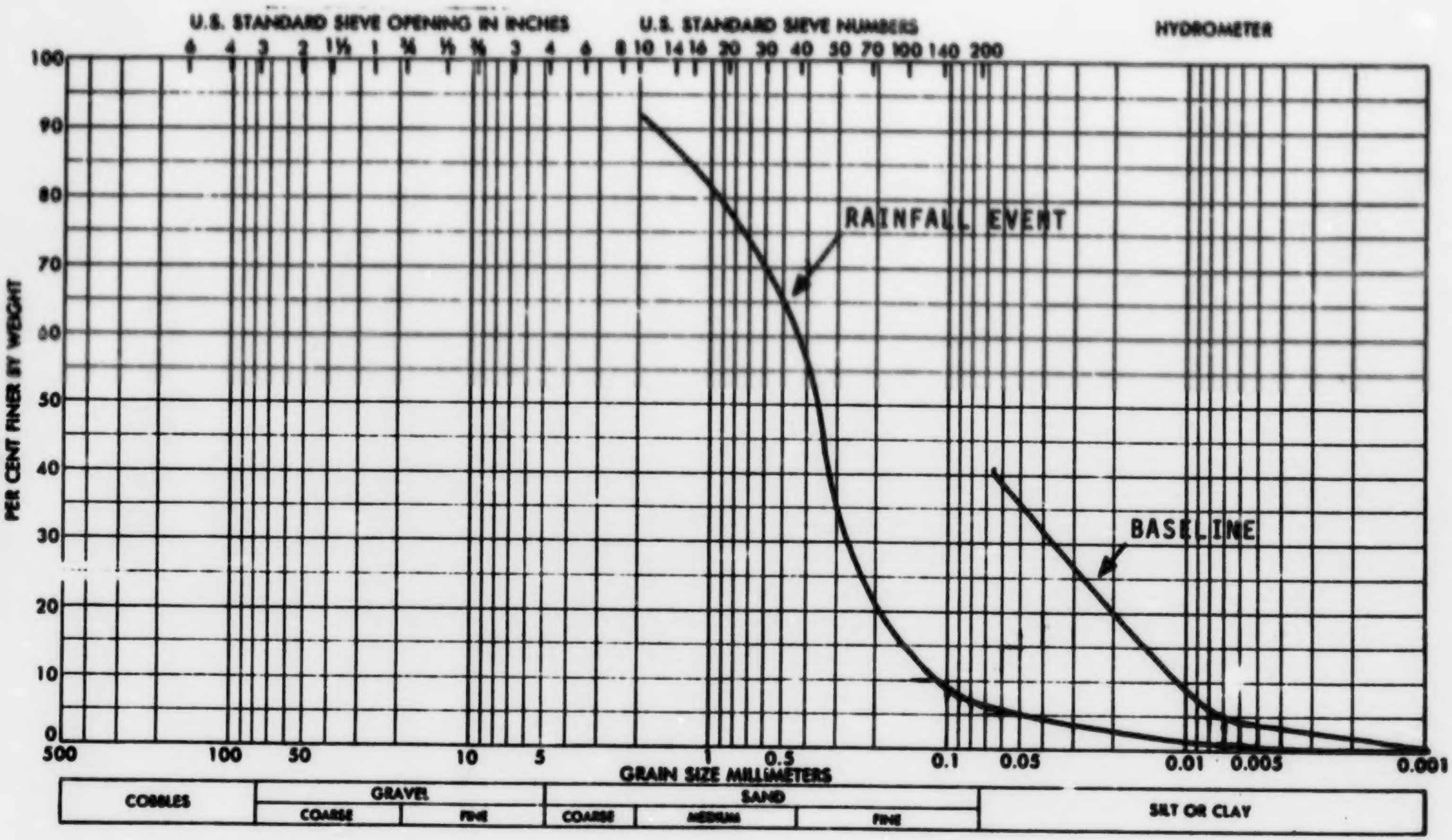

FIGURE C-12. Grain Size Distributions of the Incoming Suspended Solids During the Baseline Conditions and the Rainfall Event, Pond No. 9